Modeling nutrient requirements and measuring nutrient outputs of feedlot cattle

A Dissertation
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

Nicole M. Kenney-Rambo

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Alfredo DiCostanzo

December 2017

Acknowledgements

I have been extremely lucky to find myself surrounded with professors, colleagues and fellow students that have encouraged me to do more and be more than I thought possible throughout my graduate career. I am extremely appreciative to have had the opportunity to complete a non-traditional Ph.D. program. Many thanks to the University of Minnesota Regent's Scholarship program for tuition assistance, University of Minnesota Extension for allowing work/school flexibility and most importantly my colleague and mentor, Dr. Alfredo DiCostanzo for supporting my program and helping shape the direction of my research. In my time with U of M I had the chance to learn both in and out of the classroom and appreciate the wisdom and insight shared by the many individuals in the Minnesota beef industry I had the opportunity to work with.

This whole crazy venture would not have been possible without the support and encouragement of my husband, parents, family and friends. I am forever thankful to have such a strong support system.

Dedication

This dissertation is dedicated to my parents, husband, extended family and friends that have supported and encouraged me throughout my many years of school.

Table of Contents

List of Tables

List of Figures

Chapter 1. Review of Literature

Nutrient requirements of feedlot cattle

Introduction

A frustration for cattle feeders and nutritional consultants alike is found in the challenge of explaining deviations of animal performance compared to predicted performance derived from energy intake. While management and environmental conditions largely contribute to deviations in animal performance from the expected, an important note in interpreting the tabular value of net energy (NE) for a feedstuff or total mixed ration (TMR) is recognizing that NE values represent the average expected value based on a group of feeds rather than the NE that will be derived by a specific group of cattle consuming that feedstuff or TMR (Fox et al, 1992). Revisiting requirement equations for cattle that were not represented in the original datasets, specifically heavy weight cattle, offers the opportunity to refine predictions. Accurate prediction of nutrient requirements for animals in a particular production setting minimizes overfeeding of nutrients, increases efficiency of nutrient utilization, maximizes performance, and decreases nutrient excretion (NRC, 2016).

The California Net Energy System

A variety of feed systems have been developed in an attempt to describe the utilization of feedstuff energy by livestock. At the most simplistic level, feed can be evaluated based on total energy contained or gross energy (GE). Gross energy is the measurement of energy released as heat when an organic substance is completely oxidized to carbon dioxide and water. Gross energy is of limited use because it does not

account for energy available to the animal. Subtracting the energy lost in the feces from GE, resulting in digestible energy (DE), begins to account for energy lost through the digestion process; however, DE fails to account for losses of energy associated with digestion and metabolism of food. Metabolizable energy (ME) takes into consideration two major losses of feedstuff energy, urine energy and gaseous energy as well as fecal energy. Metabolizable energy is an improvement over DE, as it fully accounts for the energy available to the animal; however, it fails to factor in energy lost through heat produced during digestion and metabolism. Net energy ultimately accounts for energy lost through feces, urine, gas and heat. The energy flow system represents each of these steps in quantifying feedstuff energy (Figure 1.1).

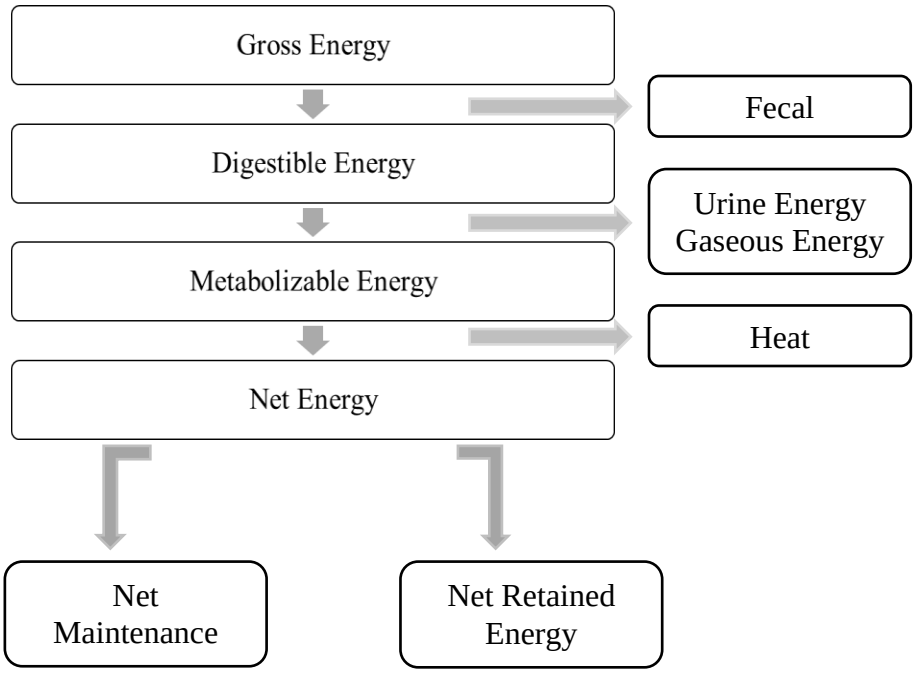

Figure 1.1 Flow of energy through an animal

The current and previous editions of the Nutrient Requirements of Beef Cattle (NRC 1984, 1996, 2000, 2016) have built upon and refined the work of Lofgreen and Garrett (1968), who developed the California Net Energy System (CNES).

"It was a pivotal accomplishment when Lofgreen and Garrett put forth the CNES. The approach simplified the complexities of biology and thermodynamics of feed utilization." Dr. Robbi Pritchard, SDSU (Pritchard, 2017).

The CNES was developed using the comparative slaughter approach, where subsets of cattle representative of the study population are harvested at various time points approaching market slaughter end-point. Body composition at each time point is determined in animals fed at two or more levels of intake, one of which approximates maintenance intake. The comparative slaughter technique allows for direct measurement of ME and retained energy (RE), as well as the determination of the efficiency of utilization of ME for RE through regression of RE on ME intake. Unlike methods that determine RE indirectly, comparative slaughter decreases the error associated with the RE value; however, considerable expense involved in conducting comparative slaughter studies make them cost prohibitive.

Net energy values of feedstuffs were developed using the "barely replacement" technique. Energy retention based on carcass specific gravity was measured in cattle fed test diets at two levels of intake above maintenance. The partial efficiency of NE utilization for growth is independent of the level of intake above maintenance (Lofgreen et al., 1963). Based on this observation, it became clear that the partial efficiency of energy used for maintenance and gain were more nearly constant than the combined value, resulting in the development of a system that assigned separate feed and animal

requirement values for maintenance and gain. Thus, separate values for the NE of maintenance (NEm) and NE of retained energy (NEre) have been developed for cattle. Retained energy use is dependent on stage of production and is further separated in to NE of growth (NEg), NE of pregnancy (NEp) and NE of lactation (NEl).

While the CNES represents a major advancement in the ability to match animal nutrient requirements with feed energy provision it is not without criticism. The simplification of a dynamic biological system into an empirical model results in the inclusion of generalities or assumptions within the model that often do not represent the inherent variation in cattle and the variety external factors that affect cattle performance. In contrast, mechanistic systems such as the Cornell Net Carbohydrate and Protein System may have the capability to more accurately predict animal requirements; however, the animal and feedstuff descriptive inputs required for such mechanistic models are more rigorous than that of empirical models and are often not practical in production scenarios. The original CNES equations are based off British cattle, with minimal genetic variation, fed during the 1950s and 1960s in a consistent environment. The influx of other genetics into the U.S. beef herd, the wide variety of environments cattle are fed in across the U.S. as well as advancements in management and technology have necessitated the addition of qualifiers and adjustments to the CNES model. The approach to determining nutrient requirements for beef cattle outlined in the current edition of the Nutrient Requirements of Beef Cattle (2016) ultimately differs little from the original approach proposed by Lofgreen and Garrett (1968).

The CNES for predicting energy requirements of growing cattle works under the assumption that cattle have a similar body composition at the same degree of physiological maturity (NRC, 2016). A transformation to equivalent shrunk body weight (EQSBW) is used to standardize body composition of cattle under evaluation to the equivalent body composition of steers used in model development. The EQSBW is calculated by multiplying shrunk body weight (SBW) by a shrunk reference weight (SRW) divided by final SBW (FSBW), where SRW is the standard reference body weight for the expected final body fat and FSBW is the SBW at the expected final body fat of the animal. This transformation is necessary, as modern cattle finish at significantly heaver weights than cattle utilized to develop the CNES. While necessary, it is difficult to apply this transformation because of the necessity of estimating FSBW, which, to do accurately, would require knowledge of the current body composition of the animal and the weight at which an animal will achieve a specific empty body fat percentage. The Nutrient Requirements of Beef Cattle (2016) uses marbling score to approximate body composition and equates a marbling score to empty body fat percentage as a means to allow for estimation of FSBW. Ultrasound has been utilized to predict percentage carcass fat from fat thickness and EQSBW. Perry and Fox (1997) found that 96% of variation in the percentage of carcass fat could be explained by carcass fat thickness and EQSBW. Earlier versions of Nutrient Requirements of Beef Cattle (1984) included separate equations for prediction of gain for steers and heifers at presumed body compositions resulting from various growth rates; however, with the inclusion of an adjustment in FSBW in the 1996 edition of the Nutrient Requirements of Beef Cattle, separate

equations are not necessary as the FSBW adjustment accounts for differences in mature size due to sex and previous growth rate.

Maintenance energy requirement

The maintenance requirement for energy is defined as the quantity of feed energy that will result in tissue energy equilibrium (NRC, 2016). The CNES is based on the expectation that cattle require a specific amount of energy for maintenance, as a function of body weight, and that cattle will utilize energy consumed exclusively to meet their energy requirement until that need has been met. The fraction of ME intake that growing cattle use for maintenance functions varies but is rarely less than 40% of energy intake (NRC, 2016). Energy consumed in excess of maintenance is directed toward accretion of lean and fat. The energy required for maintenance is calculated using the equation NEm (Mcal/day) = $0.077*SBW^{0.75}$. Shrunk body weight can be directly measured following twelve or greater hours of feed withdrawal or calculated as actual weight multiplied by 0.96. This equation predicts that maintenance requirements increase at a decreasing rate as body weight (BW) increases but it is not influenced by age, sex, breed, environmental or other conditions.

Maintenance, or basal metabolic rate (BMR), is considered equal to the heat production (HP) of the fasted animal (Lofgreen and Garrett, 1968). The BMR of an animal is defined as the metabolic rate of an adult animal at rest in a thermoneutral environment in a post-absorptive state (Hulbert et al., 2004). Measurement of BMR on large number of animals is both time-consuming and expensive; therefore, maintenance requirements have been determined by extrapolation. Heat production is measured,

indirectly or directly in cattle fed several levels of intake of the same diet and the log of daily HP regressed on daily ME intake. The y intercept of this regression is equal to HP at zero feed intake and represents an estimate of the NEm requirement. Lofgreen and Garrett (1968) estimated maintenance requirements based on five comparative slaughter trials, representing 208 head, where cattle were fed diets ranging in roughage inclusion from 2 to 40% of the diet. The range of HP of fasted cattle was determined to lie between 72 and 82 kcal per $BW^{0.75}$, with the mean value of 77 kcal per $BW^{0.75}$ adopted as the maintenance requirement. A comparison of steer and heifer maintenance requirements were examined from two comparative slaughter experiments, representing 118 steers and 188 heifers. The point of origin of the two regression equations did not differ statistically, indicating that the HP by fasting steers and heifers is not different. Therefore, the same maintenance equation was adopted for steers and heifers in the CNES model. The maintenance requirement proposed by Lofgreen and Garrett (1968) is higher than the average fasting HP of homeotherms, 70 kcal/kg $BW^{0.75}$, proposed by Kleiber (1947).

Factors that alter Maintenance

Although the CNES proposes a single equation for maintenance that accounts only for changes in BW, it is apparent that maintenance energy expenditures also vary with breed/genotype, sex, age, season, temperature, and previous level of nutrition (NRC, 2016).

Sex

Maintenance requirements between steers and heifers do not differ (Lofgreen and Garrett 1968; Garrett, 1970; Garrett, 1980; Chizzotti, 2007); however, maintenance

requirements are greater for bulls due to greater lean muscle content (ARC, 1980; CSIRO, 1990; CSIRO 2007). The Nutrient Requirements of Beef Cattle (2016) recommends an increase in maintenance requirement of 15% for bulls.

Breed

Breed differences in maintenance energy requirements have been explored extensively. The influx of Continental cattle breeds into what had previously been a primarily British type U. S. cowherd generated a number of comparisons between cattle of Continental and British genotypes. The ME required for weight or energy stasis in young bulls and heifers was on average 19% greater for Simmentals than Herefords (Jenkins and Ferrell, 1984; Ferrell and Jenkins, 1985). Other comparisons have revealed smaller differences in Simmental and Hereford maintenance requirements. Anderson (1980) reported that Simmental cattle had a 6% higher maintenance requirement than Herefords, while Byers (1982) observed only a 3% greater maintenance requirement for Simmentals. In contrast, maintenance requirements of Charolais and Hereford steers have been found to be similar (Old and Garrett, 1987) and Limousin cattle have been found to have similar maintenance requirements to Angus (Byers 1982), Hereford and Charolais (Anderson, 1980). Carstens and coworkers (1989) suggested that maintenance energy requirements of *Bos indicus* breeds of cattle are 10% lower and crossbreds have a 5% lower maintenance energy requirement than *B. taurus* breeds. A meta-regression analysis of maintenance requirements of Nellore purebreds and Nellore x *B. taurus* crossbreds indicated no difference for sex or breed but reported an average NEm of 75 kcal/kg $BW^{0.75}$(Chizzotti et al., 2008). Garrett (1971) observed that Holstein steers

required 23% more feed to maintain energy than Hereford steers. This is supported by observations of greater maintenance required by dry, non-pregnant mature Holstein cows relative to that of beef breeds of the same production phase (Solis et al., 1987). Differences in maintenance estimates for a given breed or breed cross result from method of measurements of breed effects on maintenance and confounding factors that may also alter maintenance requirements. Authors of the Nutrient Requirements of Beef Cattle (2016) caution that a generalization of relative change in NEm for a specific group of animals (e.g., *B. indicus*, *B. indicus* x *B. taurus* crossbreds) may not be appropriate if the genetics of breeds change over time; however, guidance for maintenance adjustments are provided. *Bos indicus* breeds, excluding Nellore, require up to 10% less energy than beef breeds of *B. taurus* cattle for maintenance, with crossbreds being intermediate. Dairy or dual-purpose breeds of *B. taurus* cattle require up to 20% more energy than beef breeds, with crosses being intermediate.

Previous plane of nutrition

Compensatory gain is a physiological process whereby growth accelerates after a period of restricted development, generally due to reduced feed intake, in order to reach the weight of animals whose growth was never reduced (Hornick et al., 2000). The response to previous nutritional deprivation is highly variable, likely a function of differences in severity, nature and duration of restriction (Drouillard et al., 1991). Increased feed efficiency following a period of feed restriction has been observed in heifers and steers (Drouillard et al., 1991; Murphy and Loerch 1994; Yambayamba et al., 1996; Connor et al., 2010). The mechanism(s) underlying compensatory gain are not

clearly understood. A reduction in size of metabolically active organs, thus lower maintenance energy expenditure, reduced physical activity and increased diet digestibility have been proposed as potential factors behind increased gain and efficiency during re-alimentation following feed restriction (Murphy and Loerch, 1994). The Nutrient Requirements of Beef Cattle (2016) assumes that the majority of efficiency improvements following a period of feed restriction is a function of decreased maintenance requirements and increased feed intake (NRC, 2016). In contrast, cattle fed at a high plain of nutrition from a young age, such as cattle in a calf-fed feedlot system, may have greater maintenance requirements due to larger gut mass. The gastrointestinal tract consumes approximately 20% of all incoming energy, with considerable variation observed in the literature due to differences in gut mass and fractional protein turnover (Cant et al., 1996). The Nutrient Requirements of Beef Cattle (2016) assume that NEm is 20% lower for an extremely thin animal (BCS 1) and 20% greater for an extremely fleshy animal (BCS 9) and changes 5% per BCS relative to a base score of 5. Further discussion on physiological responses to previous plane of nutrition is included in the section on Factors that Alter Growth.

Environment

Within the thermoneutral zone of cattle, energy expenditure to maintain normal body temperature is minimal, constant and independent of environmental temperature; however, when effective ambient temperature falls outside of the thermoneutral zone, cattle respond by altering behavior and physiological processes (Yousef, 1987). When temperatures exceed the upper limit of the thermoneutral zone, cattle enter heat stress and

adaptions are initiated to increase heat loss and reduce HP in an attempt to maintain body temperature within the range of normality. Initial responses to heat stress include increased water intake, sweating and respiration rate, and reduced heart rate and feed intake (Horowitz, 2002). Modification of animal endocrine status occurs in cattle exposed to longer-term heat stress. Circulating growth hormone, catecholamine and glucocorticoid levels are decreased and consequently thyroxine and triiodothyronine production is decreased which results in a reduction in the BMR and ultimately decreases HP (Yousef, 1987). Cattle experiencing heat stress decrease voluntary feed intake and consequently performance is decreased; however, decreases in feed intake alone do not appear to explain reductions in performance. Reduced feed intake during heat stress is a highly conserved response across species and has been hypothesized to be an attempt to decrease metabolic HP (Baumgard and Rhoads, 2012). Reduced feed intake explains approximately 35 to 52% of decreased milk yield during environmental-induced hyperthermia (Rhoads et al., 2009; Wheelock et al., 2010; Baumgard et al., 2011). Elevated body temperature increases tissue metabolic rate as well as respiration and heart rate in order to dissipate heat; therefore, energy requirements for maintenance increase (NRC, 2016).

In periods of cold stress HP from normal tissue metabolism and fermentation is inadequate to maintain body temperature. Animal heat loss is dependent on surface area of the animal, internal and external insulation as well as evaporative losses through respiration (NRC, 2016). Tissue insulation is a function of subcutaneous fat and skin thickness and external insulation is provided by hair coat and a layer of air surrounding

the body. External insulation is related to hair depth but also influenced by wind, precipitation, mud and hide thickness. In order to maintain body temperature, animal metabolism (NRC, 1981) and/or behavior (Karen and Olson, 2006) is modified, resulting in increased maintenance requirements.

Adjustments for temperature outside the thermoneutral zone have been included in the Nutrient Requirements of Beef Cattle (2016), although the authors recognize that results "are not completely satisfactory". A number of factors may be responsible for variability in prediction of cattle maintenance requirements based on current adjustments. Effects of season and temperature have been confounded in previous editions of the Nutrient Requirements of Beef Cattle (1984, 1996) because seasonal effects were associated with effects of temperature; however, temperature effects are generally studied in a controlled environment and consequently behavior modifications as a function of temperature are not generally observed. For example, cattle grazing rangeland have opportunities to mitigate cold stress though modification of behavior to decrease wind exposure, increase solar radiation exposure and optimize the effects of animal grouping which can potentially alter maintenance energy demands associated with cold environments. The Nutrient Requirements of Beef Cattle (2016) authors note that maintenance equations for cows on range should be used with caution as the interaction between environment and animal behavior is not accounted for in the current model. Cattle in feedlot settings have less opportunities to alter behavior based on temperature extremes; however, this is an area of research that warrants greater attention, especially as it pertains to potential differences in behavior in indoor confinement feedlot systems.

Further complicating adjustments to maintenance requirements as a function of environment is the ability of cattle to acclimate to environmental stressors, such that changes in maintenance requirements measured in short-term, controlled experiments may not accurately reflect maintenance in cattle fed in production settings. Impact of cold stress on heat loss during acute cold exposure in sheep was largely influenced by their previous thermal history (Done-Currie, 1984). In a model of thermal acclimation in cattle, length of acclimation time to short-term thermal stress and behavioral response coefficients were measured in five breeds of cattle: Hereford, Polled Hereford, Charolais, Angus and Santa Gertrudis (Senft and Rittenhouse, 1985). Breed altered acclimation time but behavioral responses did not differ amongst breeds. Polled Hereford required the greatest length of time to acclimate, 14 days, followed by Hereford and Santa Gertrudis with an acclimation time of 12 days. Charolais and Angus cattle required only 9 days to acclimate. Many modern commercial feedlot cattle are a composite of several breeds and increased crossbreeding of beef and dairy breeds for beef production is occurring. Heritability of rectal temperature in cattle exposed to heat stress is variable (da Silva, 1973; Mackinnon, et al., 1999; Ravagnolo and Misztal, 2000) and ability to adapt to thermal stress may not be a goal of genetic selection for producers. Thus, any given pen of feedlot cattle may be composed of cattle from a number of various genetic backgrounds, with varying levels of thermo-tolerance and abilities to adapt to heat or cold stress, making it difficult to apply a single maintenance adjustment for environmental stress. Furthermore, any maintenance adjustment that is directly or indirectly influenced

by breed is confounded, as an adjustment of maintenance for breed type is already accounted for in the model.

Retaining the classical maintenance equation

Given that a number of factors alter maintenance requirements, it has been proposed to alter the maintenance requirement equation based on known factors for a given group of cattle (Anderson, 2017). While changing the maintenance equation to represent the factors that alter maintenance in a given group of cattle may allow for greater accuracy in prediction of NEm and therefore NEg requirements, altering NEm would require redefining NEm feed values for each new NEm animal requirement. The NEm value of feeds is calculated by determining the quantity of a given feed required to meet energy equilibrium, which is dependent on a static NEm requirement value. Simply put, if the NEm requirement value were altered each feedstuff would thereafter have multiple NEm feed values to reflect the varying quantities required to meet energy equilibrium. Instead, adjustments on maintenance requirements are performed on feed required for maintenance, either increasing or decreasing feed available for gain based on direction of altered maintenance requirements. Ultimately, factors that alter animal maintenance requirements that are outside the scope of the adjustments discussed above are implicitly incorporated into the NEg requirement in order to maintain consistency in energy values of feedstuffs.

Protein requirements

Protein requirement systems for ruminants are more complex than that of non-ruminants due to digestion of dietary proteins and other nitrogenous compounds during

pre-gastric fermentation in the rumen. Both dietary protein and microbial-derived protein contribute to the protein flow to the abomasum, where HCL and pepsin prepare protein for further enzymatic digestion and absorption as amino acids (AA) and peptides in the small intestine. Work in monogastrics has focused on identifying the ideal amount and composition of AA reaching the small intestine (NRC, 2012); however, the capacity for the rumen to alter the AA profile of rumen degradable protein (RDP) results in difficulty in identifying the supply of AA reaching the small intestine in ruminants and consequently complicates the development of AA requirements.

Early work in protein requirements was limited to expressing requirements as a percent of crude protein (CP) in the diet as the feeding trails were conducted by measuring animal responses to graduated concentrations of CP in the diet and simplicity in calculation was required as most diets were balanced with hand calculations (Tedeschi et al., 2015). This system did not account for differences in the rumen availability and quality of dietary protein between feedstuffs and subsequently an overestimation of protein requirements were built in as a safety measure (Tedeschi et al., 2015). Advances in analytical lab equipment as well as ready access to high-powered computers allowed for the development of more advanced protein requirement systems (Tedeschi et al., 2015). The Nutrient Requirements of Dairy Cattle (NRC, 1989) and Nutrient Requirements of Beef Cattle (NRC, 1996) adopted the metabolizable protein (MP) system, originally outlined by Burroughs and coworkers in 1974, in order to account for rumen degradation of dietary protein and separate requirements of the rumen microbes and growth and maintenance needs of the animal. In comparison to the CP system, the

MP system represents a clearer understanding of the complexity of protein metabolism in ruminants (Owens and Sapienza, 2014). The MP system accounts for rumen availability of protein through division of dietary protein into RDP and ruminally undegradable protein (RUP). The RDP portion of feedstuffs consists of true protein and non-protein N sources. True protein is degraded by rumen microbe enzymatic activity to peptides and AA and eventually deaminated into ammonia (NH_3) or incorporated into microbial protein (Bach et al., 2004). Non-protein N sources are composed of N present in DNA, RNA, NH_3, AA, small peptides and urea (Bach et al., 2004). The RUP portion of feedstuffs consists of protein not readily available for microbial fermentation and rumen protected AA. The flow of MP to the small intestine includes microbial protein, RUP and endogenous protein.

The RDP requirement is related to microbial yield, which is in part driven by available energy. Thus, the original equation for RDP requirement was a function of dietary total digestible nutrients (TDN). Specifically, Buroughs et al. (1974) proposed microbial crude protein (MCP) synthesis averaged 13.05% of TDN. Further refinement of this approach continues, with adjustments based on forage inclusion in the diet proposed by Ruminant Nitrogen Usage (NRC, 1985) and the Nutrient Requirements of Beef Cattle (NRC, 1996). The Nutrient Requirements of Beef Cattle (1996) Level 1 model considers RDP requirement to equal bacterial crude protein (BCP) synthesis and therefore suggests a RDP requirement of 13% of TDN for diets containing greater than 40% forage, based on 13 g BCP synthesis per 100 g of TDN. For diets with less than

40% forage, a 2.2% reduction in BCP synthesis for every 1% decrease in forage effective neutral detergent fiber (NDF) less than 20% NDF is suggested.

Predicting performance responses to supplemental RDP using the Nutrient Requirements of Beef Cattle (1996) Level 1 model have been variable, particularly for high concentrate diets and diets consisting of low-quality forages (Mathis et al., 2000). Consequently, researchers have explored RDP requirements in relation to digestible organic matter (OM), using observed maximal digestible OM intake as an indicator that RDP requirements are met. Total digestible nutrients and digestible OM are highly correlated (Heaney and Pigden, 1963). Increases in fermentative efficiency were not observed in cattle fed prairie hay when RDP supply was greater than 11% of digestible OM (Köster et al., 1996). Digestible OM intake was maximized in cattle fed prairie hay when RDP supply, as a percentage of digestible OM, was 11.6. Other researchers found maximal digestible OM intake to be 8.2, 9.8, and 12.8% for Bermuda grass, brome grass, and forage sorghum, respectively (Mathis et al., 2000). Owens and coworkers (2014) recently published an evaluation of the Nutrient Requirements of Beef Cattle (1996) Level 1 model comparing predicted values for duodenal flow of MCP with measure duodenal flow from 118 high-concentrate diets. It was concluded that TDN intake (TDNI) accounted for only 49% of the variation in MCP yield and there was no relationship between MCP yield and TDN concentration of the diets. Owens and coworkers (2014) suggested that OM disappearance in the rumen limits microbial growth and should therefore be used to predict microbial yield. Similarly, a meta-analysis of 285 treatment means from 66 papers published in the Journal of Animal Science revealed a

linear relationship between MCP yield and true ruminal OM digested (Galyean and Tedeschi, 2014). Further, TDNI and fat-free TDNI (FFTDNI) were strongly related to true ruminal OM digested. A comparison of the Nutrient Requirements of Beef Cattle (1996) method and that of Galyean and Tedeschi (2014) revealed greater accuracy with the latter approach, although precision remains low with standard errors of prediction ranged from 25 to 30%. The Nutrient Requirements of Beef Cattle (2016) adopted the approach of Galyean and Tedeschi (2014) and recommends two separate equations based on ether extract (EE) in the diet. For diets containing less than 3.9% EE TDNI is utilized (MCP = 0.087 TDNI + 42.73), whereas for diets with greater than 3.9% EE FFTDNI is utilized (MCP = 0.0696 FFTDNI + 53.33). The inclusion of EE in the MCP model is significant as fat does not supply energy to the rumen microbes and at higher inclusion levels can depress rumen fermentation, thus decreasing MCP yield (Russel et al., 1992). The efficiency of ruminally available N capture is less than 100%; however, there has not been a consensus on the appropriate efficiency factor. The committees of the Nutrient Requirements of Beef Cattle (NRC, 1996; NRC, 2016) Level 1 solutions do not account for incomplete ruminal N capture and predicts RDP requirements to be 100% of microbial N flow (MNF) to the small intestine. Decreases in MNF have been observed in cattle fed an 80% concentrate diet when RDP dropped from 80 to 70% of the MNF (Zinn and Owens, 1983); however, in sheep fed a 55% concentrate diet, MNF was not enhanced when RDP as a percentage of digestible OM intake exceeded 11% (Rihani et al., 1993). The Ruminant Nitrogen Usage (NRC, 1985) suggested a maximum efficiency of 90%, which was adopted by the Nutrient Requirements of Dairy Cattle (1989) whereas

the most recent publication of the Nutrient Requirements of Dairy Cattle (2001) assumes an efficiency of 85% for conversion of RDP to MCP. The Level 2 solution of the most recent Nutrient Requirements of Beef Cattle edition (NRC, 2016) allows the user to input an efficiency value.

The Level 2 solutions for the 1996 and 2016 Nutrient Requirements of Beef Cattle are mechanistic solutions based on the Cornell Net Carbohydrate and Protein System, originally described by Russel and Coworkers (1992). The Level 2 solution uses ruminal degradation kinetics of carbohydrates and protein to compute TDN, MCP and RUP (NRC, 2016). The value of mechanistic models is driven by the quality of inputs available and often limited information available on feed composition necessitates reliance on empirical level solutions (Level 1) in practical applications.

Although RUP is a component of MP supply, there is not a RUP requirement. The proportion of MP supplied by MCP is dependent on RDP in the diet, and factors that alter utilization of RDP, with the balance of MP supplied through RUP. Conscientious inclusion of feedstuffs with RUP with desirable AA profiles has been utilized to improve productivity in dairy cattle to meet deficiencies in RDP AA supply relative to animal requirements (Santos et al., 1998). The Nutrients Requirements of Beef Cattle (NRC, 2016) utilizes a factorial method to determine MP requirements. The factors include metabolic fecal losses, urinary losses, scurf losses, growth, fetal growth and milk. Maintenance MP consists of metabolic fecal, urinary and scurf losses. The Nutrient Requirements of Domestic Animals (NRC, 1985) utilized a calculation based on indigestible dry matter intake (DMI) to estimate true metabolic fecal losses, as opposed to

microbial losses in the feces; however, this approach yielded unrealistically high estimates likely due to MCP production in the hindgut. Subsequent editions (NRC, 1996; NRC, 2016) utilize an equation ($MP_{maintenance} = 3.8 \times SBW^{0.75}$) based on metabolic BW. This estimate is supported by findings from nitrogen balance experiments (Susmel et al., 1993).

While requirements are discussed in terms of total MP, true requirements are for the specific AA that are supplied by MCP, RUP and endogenous protein (NRC, 2016). Total MP required is dependent on maintenance MP combined with MP required for gain. The amount of MP required for gain is dependent on the digestibility of MP in the small intestine, efficiency of absorption and subsequent efficiency of the incorporation of absorbed amino acids into net protein (NP; NRC, 2016). The efficiency of conversion of MP to NP is dependent on MP supply, the composition of MP supply, dietary energy and MP supply and physiological stage. An efficiency of 85% has been proposed for an "ideal" mixture of AA (Oldham, 1987); however, diets would rarely supply the absolute ideal AA composition. Protein deposition has been described as an energy-driven process (Gerrits et al., 1996) with the energy concentration of the diet influencing the efficiency of use of supplemental amino acids (Schroeder et al., 2006; Schroeder et al., 2007). Efficiency of AA utilization appears to be dependent on energy provision for some AA but the magnitude in change in efficiency with additional energy provision differs with specific AA. Nitrogen retention increased with provision of 3 g/day L-methionine without supplemental energy; however, efficiency of methionine use increased from 11 to 21% with provision of supplemental energy in the form of ruminal infusions of acetic or

propionic acid or abomasal infusions glucose or fat, independent of energy source (Schroeder et al., 2006). In diets limited in L-leucine, increasing the energy concentration of the diet resulted in an increase in N retention of 26 to 30% (Schroeder et al., 2007). While energy provision may positively affect efficiency of AA utilization, responses to excess MP supply are variable. Supplementation of excess AA improved the efficiency of leucine and methionine use in steers beyond what would be expected from the increased energy supplied through catabolism of excess AA (Awadah et al., 2007). Conversely, MP in excess of whole-body protein deposition may negatively affect the efficiency of conversion of MP to NP through increased energy requirements associated with AA catabolism and elimination of N through the urea cycle. Incremental efficiencies of utilization of methionine and leucine were utilized to develop the Nutrient Requirements of Beef Cattle (2016) MP to NP efficiency equation (MP to NP efficiency, % = 30 + 10,493.1 x $e^{(-0.0486 \times BW)}$, where *e* is the base of the natural logarithm). The negative exponent multiplied by BW reflects that the efficiency of utilization of AA for N retention decreases at a decreasing rate as BW increases.

Ultimately, it would be ideal if supply and requirements were expressed on an AA basis to allow the supply of AA from RUP to complement that of the supply of AA from microbial protein; however, the complexity of metabolism in the reticulorumen makes this difficult at this time (NRC, 2016). Accurate estimation of the AA available from MCP requires reliable estimation of the ruminal microbial yield, microbial protein composition, AA composition of MCP and the digestibility of microbial AA as well as an accounting of the supply of endogenous protein (O'Connor et al., 1993). Total

endogenous flow of body proteins to the small intestine has been estimated using infusion of 15^{N}-leucine to be 15 to 20% of the total N flow in lactating dairy cows (Ouellet et al., 2002; Lapierre et al, 2006). Further challenges are found in predicting the efficiency of use of specific AA for physiological processes (Tedeschi et al., 2015). From a practical standpoint, another layer of complexity is introduced when considering the broad array of feedstuffs available for use in beef cattle rations, various methods of processing and associative effects of combining feedstuffs that must be accounted for in requirement models. Greater progress has been made in this area by the dairy industry, due to the ability to recover increased ration costs through improvements in milk production or composition (Ferrareto et al., 2016). Further consideration in the development of AA requirements for beef cattle may be voluntary as a function of desires for greater gain efficiency or required through regulatory-driven reductions in manure N output.

Factors that alter animal growth

Rate and composition of tissue accretion, and therefore dietary requirements, are dynamic and a function of various combinations of the effects of diverse genotypes, inconstant environmental conditions, hormonal status, energy intake and hormonal status (Owens et al., 1995). Additional factors such as use of anabolic agents and ionophores must also be accounted for in growth models.

Maximum body size and rate of gain is genetically determined but can be altered by nutritional and hormonal factors (Owens et al., 1993). The classical empirical equation to predict BW of many different species, developed by Brody (1964), at various ages suggests that an increase in mature weight of 10% will increase daily gain by 15% in

Hereford-Shorthorn steers with an initial BW of 200 kg and a final BW of 500 kg (Owens et al., 1993). Mature weight for animals may be defined as the weight at which fat content of the empty body reaches 34 to 37% fat based on the weight at which energy content of gain was greater than 8 kcal/g; gain that would be entirely comprised of fat (Owens et al., 1993). Numerous strategies have been employed to alter rate, composition and efficiency of gain of feedlot cattle, such as use of growth-promoting agents and feed restriction at lighter weights. Altering growth patterns may result in shifts in nutrient requirements.

Hormone implants

Anabolic steroids have been used commercially for over 50 years to stimulate lean tissue deposition in growing beef cattle (Reinhardt, 2007). Active ingredients include progesterone, estrogens (estradiol, estradiol benzoate, and zeranol) and androgens (testosterone propionate and trenbalone acetate [TBA]) with various combinations of active ingredients and potencies available. Implanted cattle have greater average daily gain (ADG) and growth efficiency (Cecava and Hancock, 1994; Johnson et al., 1998; Bryant et al., 2010). Although use of steroid implants in cattle has been a common commercial practice for a great number of years and effects on performance are clearly documented, the biological mechanisms by which these advantages are achieved are not completely understood.

Changes in N retention, as a result of implantation, were observed by several researchers (Cecava and Hancock, 1994; Lobley et al., 1985). Lobley et al. (1985) observed a marked increase in N retention immediately after implantation with a

combination of TBA and estradiol-17β, which continued through week 7 of an 11-week the study; however, differences in N retention were not as large between implanted and non-implanted steers during weeks 8 through 11. This is likely explained by a simple decrease in steroid provided by the implant over time. Similarly, Cevaca and Hancock (1994) found that N retention increased 12.7% and retention as a percentage of absorbed N increased 17% with implantation of just estradiol-17β. Decreases in plasma urea N were observed 14 days post implantation. This indicates that greater amino acid N was incorporated into skeletal muscle as opposed to being converted to urea in the liver and/or less protein turnover was occurring.

Trenbolone acetate either reduced or had no effect on protein fractional synthesis rate in individual organs despite increases in total body protein gain (MacRae and Lobley, 1991). Similarly, Buttery and coworkers (1978) observed increases in total RNA expression in skeletal muscle accompanied by a decrease in fractional synthetic rate of muscle protein in female rats treated with TBA. This indicates that TBA increases protein gains by decreasing protein degradation. If it is indeed true that protein degradation is decreased, it would be expected that maintenance energy requirements would be reduced. Significantly lower heat production values, expressed per unit of body weight were observed in implanted cattle losing weight on a roughage diet as compared to control animals (Hunter and Vercoe, 1987). The amount of weight lost per day by the implanted steers was numerically, but not statistically different; however, they consumed less feed than control steers. In contrast, Lobley and coworkers (1985) found that heat production, when expressed per unit of metabolic body-weight, did not differ between steers

implanted with a combination of TBA and estradiol-17β and non-implanted steers. Inconsistencies between studies leave the hypothesis that implants decrease maintenance in doubt.

Using rats as a model, researchers have explored the difference between plasma and muscle intracellular free AA concentrations as a result of TBA treatment (Vernon and Buttery, 1978). No difference in plasma AA were detected; however, changes in muscle intracellular levels of glycine, lysine, and arginine were found to be significantly altered by TBA. Treated rats were found to have higher concentrations of plasma glycine than their untreated counterparts and lower plasma lysine and arginine concentrations. It is possible that changes in glycine and lysine concentrations were due to increased energy demands in the muscle due to the activation of intracellular signaling cascades that control muscle synthesis. Glycine demands are high under normal circumstances, anywhere from 10 to 50 times dietary intake; increased muscle synthesis mediated by steroids may increase this demand and result in increased synthesis of glycine. Alternatively, lysine concentrations may decrease because lysine is being increasingly incorporated into muscle or because lysine catabolism is increased in order to produce more acetyl-CoA which ultimately enters the TCA cycle, an energy yielding process.

Current research has focused on gene expression of insulin-like growth factor 1 (IGF-1) and its effect on downstream targets. Use of real time quantitative PCR to determine mRNA levels of IGF-1 in implanted versus non-implanted steers revealed that at day 28 post implantation, steers implanted with a combination of estrogen and androgen had 2.4-fold greater IGF-1 mRNA concentration in the longissimus muscle

(Dunn et al., 2003). Differences in IGF-1 mRNA concentration between implanted and non-implanted steers have been found as early as 12 days post implantation, when implanted with a combination of estrogen and androgen (Pampusch et al., 2003). Comparisons of non-implanted steers with steers implanted with estradiol 17β, TBA, or a combination of the two showed an interaction between implant type and time (Pampusch et al., 2008). At day 7 post implantation, steers implanted with estradiol 17β exhibited higher IGF-1 mRNA concentration than non-implanted, TBA implanted, and steers with the combination implant. Steers implanted with TBA or TBA/estradiol 17β showed no difference in longissimus muscle IGF-1 mRNA concentration compared to control steers at day 7. At day 14 there was no difference in mRNA concentrations between any of the groups. However, at day 28, steers implanted with estradiol 17β and those with the combination implant had higher mRNA concentrations than TBA or control steers, which did not differ. Clearly, the implantation effects on muscle IGF-1 mRNA levels are inconsistent. The implication of increased IGF-1 mRNA in the muscle is that of increased synthesis of IGF-1. The majority of IGF-1 present in general circulation is synthesized in the liver (Florini et al., 1996); however, IGF-1 produced locally in the muscle has the potential to act through autocrine and/or paracrine mechanisms to promote increased hypertrophy (Dunn et al., 2003; Glass, 2003).

Dunn and coworkers (2003) measured circulating IGF-1 on days 0, 14 and 28. On day 14 and 28 following implantation, implanted steers had 53 and 85% greater serum IGF-1 levels, respectively, as compared to non-implanted steers. A comparison of serum IGF-1 levels in implanted steers revealed a 54% increase from day 0 to day 28. In

another study, differences in serum IGF-1 between implanted (a combination of TBA and estradiol) and non-implanted bulls and steers were compared (Lee et al., 1990). Control bulls were found to have higher mean IGF-1 concentrations than control steers during the growing period. Implantation increased serum IGF-1 in steers and erased differences observed between control steers and bulls. A similar trend was observed in the finishing phase. These data suggest that bulls do not receive the same benefits from growth implants as steers. The authors postulate that steers show greater sensitivity to growth implants because castration deprives them of basal levels of androgenic hormones. Changes in serum IGF-1 have been measured as early as 6 days post implantation, relative to concentrations in the same steer at day 0, and remained elevated throughout a 32 day study (Johnson et al., 1998).

Cellular responses to steroid hormones, which are broadly characterized as genomic or rapid signaling responses, are mediated by receptors that initiate a complex range of cellular events upon ligand binding (Prossnitz et al., 2008). Genomic responses are characterized by changes in gene transcription that occur over hours to days, whereas rapid signaling events occur within seconds to minutes of cell stimulation (Prossnitz et al., 2008). The majority of hormones are likely to initiate both rapid signaling events and transcriptional responses via their cognate receptors (Prossnitz et al., 2008). The possibility that implantation with TBA, estradiol 17β, or a combination of the two alters IGF-1 Receptor, Androgen Receptor, or Estrogen Receptor – α expression was explored by Johnson et al., (1998). Longissimus muscle biopsies were obtained from all steers on days 0, 7, 14 and 28 post implantation. No significant differences were observed in

receptor expression for any of the treatments at any of the time points. Binding of IGF-1 induces a conformational change in its receptor tyrosine kinase, this results in trans-phosphorylation and ultimately the phosphorylation of insulin receptor substrate 1 (Glass, 2003). This in turn results in the activation of PI(3)K and production of phosphatidylinositol-3,4,5,-triphosphate (Glass, 2003). Phosphatidylinositol-3,4,5,-triphosphate activates Akt by recruiting Akt to the plasma membrane and providing a membrane-binding site, where it is phosphorylated by two different kinases, PDK1 and the mammalian Target of Rapamycin (mTOR)-Rictor complex (Glass, 2003; Sandri, 2008). Activation of Akt results in the phosphorylation of a number of substrates which ultimately have effects on protein synthesis, gene transcription, as well as cell proliferation and survival (Glass, 2003). Akt controls protein synthesis through activation of mTOR, as well as inactivation of glycogen synthase kinase 3β (Sandri, 2008). There are three separate Akt genes, Akt1, Akt2 and Akt3. Akt1 and Akt2 are expressed in the skeletal muscle at higher levels than Akt3, which is primarily expressed in the brain (Sandri, 2008). Insulin-like growth factor 1 has the capacity to activate Akt1 (Sandri, 2008). The mTOR pathway is activated by Akt through direct phosphorylation and inhibition by Akt of tuberous sclerosis 2, a negative regulator of mTOR (Hahn-Windgassen et al., 2005). Akt also activates mTOR by down-regulating AMP-activated protein kinase, which is an activator of tuberous sclerosis 2 (Hahn-Windgassen et al., 2005). A major function of mTOR is to promote mRNA translation (Wang and Proud, 2006). The mTOR pathway controls a number of components involved in the initiation and translation steps of protein synthesis (Bodine et al., 2001; Wang and Proud, 2006).

Activation of mTOR results in an increase in protein translation in skeletal muscle by two mechanisms, both of which were demonstrated in vivo by Bodine et al. (2001) using rats as a model. Signaling mediated by mTOR activates protein synthesis both in the short-term, by increasing rate of translation, and longer-term (minutes versus hours) by increasing the translational capacity of cell through increased levels of ribosomes (Wang and Proud, 2006). First, mTOR activates p70S6K, P70S6K targets S6K which upregulates the translational machinery. Secondly, mTOR causes phosphorylation of PHAS-1/4E-BP1 which releases it from an inhibitory complex with EIF4E, allowing EIF4E to initiate translation. complexes at the 5' end of mRNA and allow for the location of the start codon by the ribosome through helicase activity (Wang and Proud, 2006). Ultimately, the significance of activating the signaling cascade that leads to upregulation of mTOR activity is the promotion of muscle hypertrophy. The IGF-1/PI(3)K/Akt signaling cascade is not the only means of mTOR activation, AA have the capability to act as independent nutritional signals and modulate protein synthesis through mTOR (Anthony et al., 2001). Infusions of glucose and various combinations of AA in post-absorptive young rats revealed that mixtures of essential AA and branched chain AA stimulated muscle protein synthesis while mixtures of non-essential AA, as well as singular infusions of methionine, glutamine and alanine had no effect (Garlick and Grant, 1988). Further work demonstrated that leucine alone is responsible for the observed increases in protein synthesis attributed to branched chain AA (Garlick, 2005). It is possible that branched chain AA, specifically leucine, are involved in mTOR signaling while other AA are not due to their unique catabolism. Unlike other AA, branched chain

AA are catabolized in the muscle due to the absence of branched chain amino transferase in the liver. Leucine modulates mTOR activity without affecting any signals upstream of mTOR, indicating it works via an independent pathway (Kimball and Jefferson, 2004). It was proposed that leucine modulates mTOR by causing the disassociation of tuberous sclerosis 2 from tuberous sclerosis 1, rendering tuberous sclerosis 2 inactive (Kimball and Jefferson, 2004). As mentioned previously, tuberous sclerosis 2 is a potent inactivator of mTOR. Further work in this area led to the proposal that leucine's effect on tuberous sclerosis 2 is a result of inhibition of AMP-activated protein kinase, which serves as an activator of the tuberous sclerosis 1 / tuberous sclerosis 2 complex (Han et al., 2008). Leucine is metabolized in the muscle and used for synthesis of ATP which results in decreased AMP-activated protein kinase activity (Han et al., 2008). Leucine's ability to increase protein synthesis through mTOR signaling has potential significance for beef cattle production systems because of the high concentration of branched-chain AA in distillers grain, a byproduct of ethanol production that has become a common protein supplement, and at times energy source, in beef cattle diets. Early work regarding the effects of growth implants on leucine metabolism revealed that implanted steers utilized less leucine for muscle synthesis post implantation (Lobley et al., 1985). It is possible that a greater portion of leucine was directed toward mTOR signaling functions rather than protein synthesis. The potential of an additive response in increased muscle synthesis via up-regulation of mTOR singnaling mediated by both growth implants and leucine should be further explored. While Han et al. (2008) observed no synergistic

effects of combined IGF-1 and leucine treatments in pigs, this may still prove to be an important area of research in beef cattle.

The primary biological mechanism driving this increase in lean muscle gain in implanted beef cattle appears to be the mTOR pathway via IGF-1. The advancement in knowledge from initial performance studies to current studies concerning the effects of growth implants on intracellular signaling has been substantial, however many of the finer details of intracellular signaling and interactions between the various mechanisms are not fully understood at this time.

Beta-adrenergic agonists

Beta adrenergic agonists (β-AA) are utilized in cattle and swine to increase feed efficiency, muscle mass and carcass leanness (Armstrong et al., 2004; Johnson et al., 2014). Beta adrenergic receptors (β-AR) are members of a large super family of G protein-coupled receptors that are naturally targeted by epinephrine and norepinephrine (Johnson et al., 2014). Beta receptors are found throughout the body; however, the distribution of β-AR varies with tissue and the species of animal (Mersmann, 1998). To date, three subtypes of β-AR have been identified, β1, β2 and β3. In cattle, greater than 99% of β-AR in skeletal tissue and greater than 90% of β receptors in adipose are β2 receptors; whereas in pigs, approximately 60% of the total number of β-AR are β1, with the remainder primarily comprised of β2 receptors (Mersmann, 1998; McNeel and Mersmann, 1999). Curently, two β-AA are FDA approved for use in beef cattle, ractopamine (Optaflexx, Elanco Animal Health, Greenfield, IN) and zilpaterol (Zilmax, Merck Animal Health, Madison, NJ); however, zilpaterol was voluntarily removed from

the market by the manufacturer in 2013. Additional non-approved β-AA include clenbuterol, L-644, 969, and cimaterol. Zilpaterol is a β2-AA, whereas ractopamine is a β1-AA. A meta-analysis of 32 studies with steers and 16 studies with heifers fed ractopamine demonstrated that DMI was not affected in either gender, whereas ADG, feed efficiency, dressing percentage and longissimus were increased by feeding ractopamine (Pyatt et al., 2013a, b). In steers, relative to controls, live weight gain increased by 3.4, 6.8, and 10.2 kg and carcass weight by 3.1, 6.1, and 9.2 kg with ractopamine doses of 100, 200, 300 mg/day, respectively. In heifers, relative to controls, live weight gain increased by 2.7, 5.4, and 8.1 kg and carcass weight gains increased by 2.1, 4.3, and 6.4 kg with ractopamine doses of 100, 200, 300 mg/day, respectively. Zilpaterol increased live weight by 9.5 kg, carcass weight by 14.6 kg, longissimus muscle area by 8.3 cm^2, and dressing percentage by 1.5 units in steers (Vasconcelos et al., 2008, Elam et al., 2009, Montgomery et al., 2009). In heifers, zilpaterol increased live weight by 5.2 kg, carcass weight by 11.1 kg, longissimus muscle area by 5.7 cm^2, and dressing percentage by 1.5 units (Montgomery et al., 2009; Rathmann et al., 2012). The greater response observed in cattle fed zilpaterol, compared to ractopamine, is attributed to β-AR sub-type of each respective product relative to receptor type abundance in cattle (Johnson et al., 2014).

Beta adrenergic agonists bind to β-AR, resulting in an exchange of guanosine triphosphate for guanosine diphosphate resulting in the activation of adenylate cyclase, an enzyme that is responsible for the production of cyclic adenosine monophosphate (cAMP), a major intracellular signaling molecule (Mersmann, 1998). Most of the actions

of β-AA are attributed to the observed increase in cAMP (Johnson et al., 2014). As the concentration of cAMP is increased, it binds to the regulatory subunits of protein kinase A (PKA) resulting in the phosphorylation of serine residues of several metabolic hormones (Mersmann, 1998). Downstream targets of activated PKA include hormone sensitive lipase, the rate-limiting enzyme for adipocyte triacylglycerol degradation, and acetyl CoA carboxylase, the rate-limiting enzyme for long chain fatty acid biosynthesis. Hormone sensitive lipase is activated by PKA while acetyl CoA carboxylase is de-activated by PKA, cumulatively resulting in the depression of triacylglycerol accumulation and concomitant release of fatty acids (Oscar, 1995); ultimately resulting in the partitioning of energy away from adipose tissue toward lean tissue accretion.

The number of muscle fibers are fixed at birth; thus, increases in lean tissue must come from either DNA accumulation, such as recruitment of satellite cells, or increasing the ratio of protein to DNA in muscle fibers. Lean tissue accretion in cattle fed β-AA is accomplished through an increase in the ratio of protein to DNA (Walker et al., 2010). This suggests that β-AA stimulates increased protein synthesis, reduces protein degradation, or potentially both (Mills, 2002). Ractopamine increased protein synthesis without affecting protein degradation in pigs (Bergen et al., 1989). Similarly, both ractopamine and clenbuterol, a β2-AA, increased myosin light-chain mRNA abundance in the longissimus muscle of beef cattle (Smith et al., 1989; Smith et al., 1995). Clenbuterol reduced the breakdown of myofibrillar protein in fasted rats (Benson et al., 1991) and reduced the activity of the ubiquitin-protease pathway, the primary muscle catabolism mechanism in the cytolsol and nucleus in fast twitch muscles in rats

(Yimlamai et al., 2005). In bovine skeletal muscle, inclusion of cimaterol resulted in increased activity of both calpain II and calpistatin (Parr et al., 1992). Decreased activity of calpain I and increased activity of calpain II and calpistatin result from inclusion of cimaterol in the diet was observed in other species, such as sheep, chickens and rats (Bardsley et al., 1992). Calpains are calcium dependent proteases that are involved in the degradation of skeletal muscle, specifically in the breakdown of myofibrillar proteins (Parr et al., 1992). Calpain I and calpain II is activated at millimolar and micromolar levels of Ca^{2+}, respectively (Parr et al., 1992). Calpastatin is a specific inhibitor of calpains (Hanna et al., 2008). Both increased protein synthesis and decreased protein degradation appear to play a role in β-AA-mediated hypertrophy, with differences in specific β-AA attributing to the variation observed in the literature.

In addition to altering protein turnover, β-AA shift muscle fiber type, which is of importance due to potential implications of fiber type distribution on meat palatability. Fiber type is categorized based on myosin heavy chain (MyHC) type, MyHC are a component of myosin, the major structural protein of the sarcomere. Four types of MyHC were identified in adult mammalian skeletal muscle, MyHC-1, -2a, -2b and -2x (Tanabe et al., 1998). The MyHC-1 fiber type is associated with red, oxidative muscle fibers, which are primarily used in aerobic metabolism, whereas Type -2a, -2b and -2x isoforms are associated with anaerobic, fast-twitch muscle fibers (Beermann, et al., 1987). Type -2x and -2b MyHC have larger diameters, relative to -1 and -2a isoforms, resulting in greater shear force value (Calkins et al., 1981). Rathmann and coworkers (2009) found that MyHC-2a decreased while MyHC-2x increased in steers fed zilpaterol. Similar shifts

in muscle fiber type were also observed with ractopamine use in pigs (Aalhus et al., 1992).

The maximal response of β-AA is dependent on the type of β-AA, dose and duration of a sustained dose (Smith et al., 1989). Beta adrenergic agonist-mediated increases in cAMP are transient because exposure to a constant dose of β-AA results in acute desensitization of β-AR (Johnson et al., 2014). Long-term exposure at elevated doses of β-AA leads to internalization of β-AR from the cell surface and down-regulation of β-AR mRNA abundance (Hausdorff et al., 1990). Regardless of chronic or acute desensitization, responses to β-AA are limited in duration. Optaflexx (ractopamine; Elanco Animal Health) is labeled for use in beef cattle for the last 28 to 42 days on feed while Zilmax (zilpaterol; Merck Animal Health) is labeled for use in beef cattle for the last 20 to 40 days on feed. The optimal feeding duration for ractopamine in cattle is 28 days (Bittner et al., 2017). Similarly, limited appreciable additive gains in carcass measurements have been observed by feeding zilpaterol beyond 20 days (Elam et al., 2008; Vasconcelos et al., 2008; Rathmann et al., 2009). Steroid implants and β-AA have similar physiological responses of muscle hypertrophy, but appear to have difference mechanisms of growth (Johnson et al., 2014).

Previous level of nutrition

Compensatory gain is a physiological process whereby growth accelerates after a period of restricted development in order to reach the weight of animals whose growth was never reduced (Hornick et al., 2000). The response to previous nutritional deprivation is highly variable, likely a function of differences in severity, nature and

duration of restriction (Drouillard et al., 1991). Increased feed efficiency following a period of feed restriction has been observed in heifers and steers (Drouillard et al., 1991; Murphy and Loerch 1994; Yambayamba et al., 1996; Connor et al., 2010). The mechanism(s) underlying compensatory gain are not clearly understood. A reduction in size of metabolically active organs, thus lower maintenance energy expenditure, reduced physical activity and increased diet digestibility were proposed as potential factors behind increased gain and efficiency during re-alimentation following feed restriction (Murphy and Loerch, 1994).

The effects of limiting intake of MP or NE for gain for varying durations indicated that degree of compensatory gain was similar for cattle restricted for 77 days regardless of nutrient restricted; however, longer (126 to 154 days) restrictions in energy improved finishing performance with minimal impacts on subsequent performance of steers previously limited in MP (Drouillard et al., 1991). Resting metabolic rate was lower in feed restricted heifers, as compared to ad lib fed controls, during feed restriction and 15 days post re-alimentation but did not differ at 36 days post re-alimentation (Yambayamba et al., 1996). This is supported by observations that efficiency of ME utilization remained high for at least 4 weeks after re-alimentation in steers that had experienced feed restriction and then decreased steadily to non-restricted control levels thereafter (Carstens et al., 1989). It has been postulated that maintenance requirements decrease during feed restriction due to a reduction in size of gastrointestinal organs, although differences in liver weights of feed-restricted steers relative to that of non-restricted steers has been inconsistent (Murphy and Loerch, 1994; Connor et al., 2010).

The endocrine response during feed restriction and re-alimentation has been described. During feed restriction plasma insulin concentration is decreased, reflecting lower dietary energy and protein supply, which results in decreased IGF-I concentration, despite increased growth hormone (GH) concentration (Breier and Gluckman, 1991; Yambayamba et al., 1996). Enhanced GH concentration during a low plane of nutrition was associated with an increase in amplitude of GH release, rather than frequency of release, and this increase has been associated with a decrease in the negative feedback control of hypothalamic somatostatin (Hayden et al., 1993). Expression of GH receptors in the liver is acutely responsive to nutritional status and becomes refractory to GH during feed intake restriction, resulting in an uncoupling of the GH-IGF-1 axis (Hornick et al., 2000; Butler et al., 2003). Consequently, IGF-1 concentration is reduced while the removal rate of GH is also reduced due to decreased binding at receptor sites (Hornick et al., 2000; Butler et al., 2003). Following re-alimentation, GH remains elevated, with the length of time to return to control levels dependent on duration and severity of feed restriction (Blum et al., 1985; Breier et al., 1986; Yambayamba et al., 1996). High GH concentration combined with increased insulin from increased feed intake and/or increased nutrient density of the diet increases the affinity of GH receptors and therefore increases IGF-1 production (Yambayamba et al., 1996). Circulating IGF-1 is primarily responsible for mediating the anabolic functions of GH and stimulating the rapid growth following periods of feed restriction (Hannon et al., 1991; Yambayamba et al., 1996; Jiang and Ge, 2014).

Conversely, cattle fed at a high plain of nutrition from a young age, such as cattle in a calf-fed feedlot system, may have increased maintenance requirements due to increased gut mass and reduced gain efficiency due to composition of gain consisting of greater amounts of fat. The gastrointestinal tract consumes approximately 20% of all incoming energy, with considerable variation exists in the literature due to differences in gut mass and fractional protein turnover (Cant et al., 1996). Gill and coworkers (1993a, b) explored the effects of plane of nutrition following weaning on Angus-crossbred steers of a narrow genetic base in a series of comparative slaughter studies. Cattle were placed in the feedlot at five different stages. The first group were placed directly in the feedlot after being weaned at day 105. The remaining groups were weaned at day 240 and were either placed directly in the feedlot, entered the feedlot after grazing wheat pasture for 112 days, or grazed native winter range plus summer grass for 68 or 122 days. Representative animals from each group were slaughtered at feedlot entry and following finishing to a constant degree of finish. Body protein mass was closely related to body weight, independent of nutritional strategy; however, while fat mass increased with age/weight it was dependent on energy intake during the background period. Calves that grazed for the full summer season had heavier initial weights entering the feedlot but lower fat mass. Early weaned steers had a higher percentage of fat at finish and lower percentage of body protein. Early weaned and normal weaned feedlot direct calves had the lowest empty final body weights with significantly greater percentage of empty body fat. Early weaned and normal weaned feedlot direct steers had 34.8 and 32.1% empty body fat at finish, respectively, whereas backgrounded cattle ranged in empty body fat

from 25.1 to 26.3%. Cattle fed high energy diets at younger ages/weights deposit greater amounts of fat and therefore reach physiological maturity at lighter weights.

Adjustments to Nutrient Requirements of Beef Cattle (2016) nutrient requirement equations

Hormone implants

Observed differences in lean protein accretion, as a result of steroid implantation, generated interest regarding whether MP requirements are affected by growth promoters. Cecava and Hancock (1994) designed an experiment to test this hypothesis. Supplementing a corn silage and high moisture corn-based diet with urea or varying combinations of soybean meal and feather meal were compared. Feather meal is significantly higher in RUP, as compared to soybean meal. Increasing substitution of soybean meal with feather meal resulted in a decrease in total N digestibility; however, N retention as a percent of N absorbed increased. This is likely explained by the difference in AA profiles reaching the small intestine as a result of dietary treatment. Nitrogen provided in the form of urea resulted in the lowest N retention and greatest plasma urea N concentration. The comparatively fast catabolism of urea to NH_3 in the rumen and subsequent absorption in the blood resulted in greater synthesis of urea in the liver, via the ornithine cycle, and ultimately resulted in decreased N retention. In contrast, Cecava and Hancock (1994) observed no interaction between implantation and protein source in a feedlot study, in which the same supplements as outlined above were utilized. This is consistent with other work, which shows that response to increased RUP protein is inconsistent in implanted steers (Lowman et al., 1985). Similarly, the various Nutrient Requirements of Beef Cattle versions (NRC, 1984; NRC, 1996; NRC, 2016) have not

included adjustments for growth implants in protein requirement. Implants change both rate of gain and feed intake, with greater enhancement of rate of gain resulting in improved feed efficiency, but do not appreciably alter nutrient utilization (NRC, 1996). Instead, growth implants alteration of nutrient requirements is related to a shift in FSBW at 28% empty body fat, thus shifting potential mature size which can alternately be thought of as decreasing physiological maturity at a given number of days on feed relative to non-implanted contemporaries (NRC, 2016). Steers used in the development of the nutrient requirement equations of Lofgreen and Garrett (1968) received estrogen-based implants. To account for use of implants containing androgen components or cattle finished without use of implants, corrections of final body weight at a constant finish are included in current Nutrient Requirements of Beef Cattle equations (NRC, 2016). The FSBW is decreased by 25 to 45 kg in non-implanted cattle, no adjustment is necessary for cattle implanted with estrogen only products, and FSBW is increased 24 to 45 kg in cattle implanted with combination implants containing TBA and estrogen.

Beta-adrenergic agonists

Increased protein deposition in response to β-AA use would presumably increase AA requirements. In fact, an increase in supply of ileal digestible lysine is suggested for pigs to maximize response to ractopamine (NRC, 2012). Limited data is available on the relationship between nutrient supply and response to β-AA in cattle. In feedlot heifers fed ractopamine, varying amounts of MP (688, 761, 808 g/d) did not alter ractopamine response (Walker et al., 2006). Evidence of altered in vitro rumen fermentation with ractopamine suggests that ractopamine may affect RDP requirements (Walker and

Drouillard, 2010); however, more research is necessary to determine if the magnitude of changes in ruminal fermentation are great enough to elicit measurable changes in requirements in an animal model. It is possible that detecting measurable changes in requirements may be accomplished more readily if approached from the level of AA requirement, rather than MP requirements. At this time, a single study exploring the impact of AA supply on β-AA response in cattle has been published. Hosford and coworkers (2015) observed increased ADG in steers supplemented with rumen-protected lysine and methionine when receiving zilpaterol. The Nutrient Requirements of Beef Cattle (2016) addresses the alteration of cattle growth with β-AA use through an adjustment in FSBW, reflecting the increase in carcass transfer observed with β-AA use but does not address potential differences in MP or AA requirements. Final shrunk body weight is increased by 6 to 36 kg with β-AA use (NRC, 2016).

Previous level of nutrition

Energy intake above maintenance during the stocker and backgrounding phases varies considerably. In general, most of the improved efficiency of gain observed with compensatory gain is a function of decreased maintenance requirements and increased feed intake (NRC, 2016). Thus, a NEm adjustment for previous nutrition is included in the model. The Nutrient Requirements of Beef Cattle (1996, 2016) assume that NEm is 20% lower for an extremely thin animal (BCS 1) and 20% greater for an extremely fleshy animal (BCS 9) and changes 5% per BCS relative to a base score of 5. Additionally, corrections are provided for FSBW based on either extended periods of slow gain or continuous provision of high energy diets beginning in weaning, as is common in calf-fed

feeding systems. Final shrunk body weight is increased by 25 to 45 kg for cattle subjected to extended periods of slow gain and decreased by 25 to 45 kg for cattle in calf-fed systems.

Digestion modifying compounds

Compounds that modify digestion also have the potential to change efficiency of nutrient use and therefore indirectly alter animal nutrient requirements. Of particular focus are ionophore antibiotics due to their widespread use in conventional feedlot diets. The USDA NAHMS 2011 Feedlot Survey reported that 90.1% of cattle placed in feedlots are fed an ionophore (USDA, 2013). Ionophores are carboxylic polyether compounds that improve feed efficiency by altering the rumen bacterial population resulting in a shift in volatile fatty acid production toward greater propionate at the expense of acetate and butyrate production. The Nutrient Requirements of Beef Cattle (2016) recommends dietary ME be increased by 2.3% for monensin and 1.5% for lasalocid and laidlomycin propionate.

Manure as fertilizer

Introduction

In light of volatility in commercial fertilizer prices, integrated crop and livestock operations are increasingly recognizing the value of manure as a fertilizer, which is primarily driven by content of N, P and K. In the past, the cost of hauling manure in relation to its relative value as fertilizer limited spreading to fields directly adjacent to animal facilities. Although limitations in distance hauled still exist, a greater emphasis on both the value of manure as a fertilizer and best management practices to minimize

environmental overload of manure nutrients has resulted in greater consideration in manure handling practices.

Beyond environmental and financial considerations, on a strictly N, P, and K basis, additional incentives to utilize manure as fertilizer have been identified. Although P is a ubiquitous element, phosphate fertilizer is not a limitless resource. It has been estimated that the world supply of phosphate fertilizer will reach its peak in 2033 (Cordell et al., 2009) or it did so in 1989 (Déry and Anderson, 2007). Currently, phosphate demand is expected to increase 2.2% annually from 2014 to 2018 (FAO, 2015). Increasing nutrient recycling through animal manure has been identified as one, if not the most important, strategy to prevent food scarcity resulting from reduced phosphate fertilizer supplies (Cordell et al., 2009).

Further benefits of an integrated crop and livestock system include the addition of organic matter and S through fertilization with manure. Sulfur deficiencies in corn and soybean production have been identified as a result of decreased atmospheric concentrations of S, reduced soil organic matter, high rates of N fertilization and reduced soil organic matter as well as intensified crop production through the introduction of high yielding genotypes and more intensive crop rotations (Scherer, 2001; Divito et al., 2015). Traditionally, S fertilization was not recommended in Minnesota except in areas with coarse-textured soil (Rehm et al., 2006) based on research that showed improvements in corn grain yield on sites with sandy soil but not those with silt loam texture (O'Leary and Rehm, 1990). More recent work suggests S application improved yields in a variety of soil types (Kim et al., 2013). Both corn and soybean yield responses have been observed

with the application of 30 kg S/ha in moldboard and striptilled fields in fine textured soils regardless of tillage system (Strock, 2008) or 11 to 34 kg S/ha in fields representing a variety of soil types (Sawyer et al., 2012). Co-products from ethanol and sweetener production are a source of moderate- to high concentration of dietary S, and are used prevalently throughout the upper Midwest in feedlot diets at moderate- to high inclusion rates, resulting in an additional opportunity to improve crop yields through integrated feedlot and crops systems. Linear increases in fecal and urine S output have been observed in diets including wet distillers grains plus solubles (WDGS) up to 60% of diet dry matter, as compared to a dry-rolled corn control diet (Spiehs and Varel, 2009).

Environmental impact of manure nutrients

Nitrogenous compound emissions from manure pose both health and environmental risks, with the primary forms of concern being nitrates, NH_3 and nitrous oxide (N_2O). Contamination of drinking water with nitrates results in the development of methemoglobinemia in infants, a condition that results in a decrease in red blood cell release of oxygen to tissues, and has also been implicated in a number of other adverse health effects in both children and adults (Ward et al., 2005). Additionally, high levels of nitrates in surface waters contributes to eutrophication, which may result in hypoxia and consequently death of aquatic animals (Randall and Mulla, 2001). The volatilization of N to NH_3 poses air quality concerns, ranging from odor complaints to respiratory complications (Arogo et al., 2006). Nitrous oxide, a greenhouse gas, is produced by microbial nitrification and denitrification (Ayadi et al., 2015a). Manure from feedlot beef

production contributes to environmental nitrogen pollution directly from the feedlot surface as well as through nutrient run-off or leaching after application as fertilizer. Both volatilization of N to NH_3 and runoff, as a consequence of precipitation, contribute to N loss from the feedlot surface of open lots. Total N loss is dependent on the time of year, with estimates of 60 to 70% excreted N loss from open lot pen surfaces during the summer months, compared to only 40% of excreted N loss from November to May (Erickson and Klopfenstein, 2001).

The form of total N loss is dependent on environmental conditions. Nitrogen volatilization increases with higher temperatures, as well as greater wind speeds and rainfall due to evaporation (Arogo et al., 2006), thus a greater proportion of N loss during the summer months would be expected to be a result of volatilization. Estimates of summertime NH_3 volatization range from 51 to 68% of dietary N in Nebraska (Bierman et al., 1999; Erickson and Klopfenstein, 2001; Farran et al., 2006). A two-fold increase in NH_3 emissions from open lots in the High Plains was observed during summer months, as compared to the winter months (Todd et al., 2011). In contrast, N loss to volatilization is low during winter months but an increase in N runoff is observed. Bierman and coworkers (1999) estimated winter NH_3 volatization was only 35% of dietary N intake. Through use of a simulated manure storage model with radioisotope labelled urine, it was estimated that 84% of total NH_3-N losses originate from the urine portion of manure (Ayadi et al., 2015a). Nitrogen runoff during the winter is 10 times greater than rainstorm runoff during warmer months (Gilbertson et al., 1971). It is estimated that approximately 3% of total N is accounted for in runoff from the surface of open lots (Gilbertson et al.,

1971; Erickson and Klopfenstein, 2001). Stocking density also has an effect. Decreasing space allotment from 60 m^2/head to 30 m^2/head increased the incidence of winter manure nutrient run-off by 130 to 170% but did not impact run-off following rain events (Gilbertson et al., 1971). It has been estimated that 10 to 16% of excreted N remains on the pen surface of open lots following cleaning (Bierman et al., 1999), presumably due to N migration down into pen soil, which may result in leaching into ground water.

A smaller body of work has been generated on the environmental impact of N in bedded pack feedlot facilities, with available literature suggesting that seasonal and bedding source interactions occur. A three-fold increase in *in vitro* NH_3 concentration of simulated bed packs was observed in bed packs maintained at 40° C, as compared to simulated bed packs maintained at 10° C (Ayadi et al., 2015b). Additionally, a difference in NH_3 concentration accumulation over time was observed at high and low temperatures. At 40° C, NH_3 concentrations peaked between 22 and 46 hours following a weekly addition of manure and urine; whereas at 10° C, NH_3 concentrations following addition of manure and urine was not observed until hour 142 (Ayadi et al., 2015b). A similar trend in peak N emission was observed in simulated straw-bedding packs, with peak emissions occurring at day 2 and 4 post manure application with bedding rates of 1.5 and 2.5 kg/head/day, respectively (Dewes, 1999). Ammonia concentration of air samples collected from the pen surface of commercial deep-bedded monoslope feedlots varied considerably, with no specific area of the pen having consistently higher readings, but were found to decline significantly between 4 and 7 hours after cattle were removed from the pen (Spiehs et al., 2011). The authors postulated that areas with high NH_3

concentration measures were a reflection of recent animal urination in that area. Ammonia concentration in air samples of the commercial bed-pack facility were consistent with in vitro data, with the highest concentrations observed during warm months, lowest during cold months, and intermediate during months with moderate temperatures. Ammonia concentrations above a simulated bed pack were dependent on the type of bedding used, with higher NH_3 concentrations observed in bed packs maintained with corn stalks as compared to soybean stubble (Ayadi et al., 2015b). The authors attribute this difference to greater availability of protein and higher moisture content of corn stalks, as compared to soybean stubble. Measurement of N_2O of concentrations of a simulated bed pack at 10 and 40° C showed a 1.5-fold increase with temperature (Ayadi et al., 2015b), which was proposed to be a function of microbial activity, an assertion that is supported by evidence that the rate of microbial activity in swine manure increases with higher temperatures (Ni et al., 1998).

The N to P ratio in manure does not match the nutrient requirements of most agronomic crops and as a result long-term application of manure at rates designed to meet crop N requirements has resulted in soil P levels beyond optimal ranges in some areas of the United States (Sharpley et al., 1996). Phosphorus runoff from agriculture is a high priority issue because P is the main contributor to cultural eutrophication, which impacts the safety of drinking water, causes mass fish kills, disrupts ecosystems and decreases the recreational value of bodies of water (Sharpley et al., 1994). Eutrophication is a normal part of the aging of a body of water; however, increased incidences of eutrophication with a greater frequency of the development of associated harmful algae blooms have

been observed in areas with high density of agriculture (Anderson et al., 2002). Harmful algae blooms release toxins and metabolites that have been linked to human poisonings through direct water consumption or through the consumption of contaminated fish (Anderson et al., 2002).

The primary routes of P loss from agricultural land is surface runoff, which can occur directly from the feedlot surface or crop ground, and erosion of crop ground (Sharpley et al., 1994). Similar to N, winter runoff of P has been observed to be approximately 10 times greater than general rain runoff (Gilbertson et al., 1971). Field runoff is dependent on management factors such as method of application, rate and time of application (Sharpley et al., 1994). The form of P dictates availability for crop utilization. Inorganic P, which primarily consisting of orthophosphates, is in most cases immediately available for plant uptake (Daverede et al., 2004). Inorganic P is primarily characterized as being dissolved P, although a small percentage may be insoluble and therefore unavailable for plant uptake. Phosphorus in feedlot manure or composted manure is primarily in the inorganic form, with estimates of inorganic P greater than 70% of total P (Eghball, 2003). Total P from beef manure has been found to be 80 to 100% available for crop utilization and is generally estimated to be 80% available when developing manure management plans (Mallarino et al., 2014). Although P runoff remains the primary water quality risk with field application of manure, P leaching has been observed, with a greater P migration observed in sandy soils (Davis et al., 1997; Ferguson et al., 2005).

Manure output

Although a number of studies report various characteristics of manure, limited data is available on manure output. Estimated annual manure production per head space in various facilities is reported by MWPS (2004) for outdoor lot (manure yield: 2.7 ton/head), manure pack (manure yield: 4.5 ton/head) or confinement pit (manure yield: 9,463 L/head) cattle feedlots; however, there is little data available for comparison, particularly for confinement feedlot facilities.

In a summary of 18 experiments spanning a 10-year period, gross manure and N output were reported for summer and winter seasons for an open lot (Kissinger et al., 2006). Summer manure output was less than winter manure output, with 6.8 and 14.5 kg of manure as-is produced per head per day for summer and winter seasons, respectively, which translated to 4.7 and 11.9 kg of manure on a dry matter (DM) basis for summer and winter seasons, respectively. It is important to note that the reported CV for as-is and DM manure production ranged from 47 to 49%, highlighting the variability in manure output even within in a single system. Similarly, N output in kg/head/day was greater in the winter and CV of 48% was reported in the summer compared to 33% in the winter. In comparison, the estimate for daily as-is manure output by the Midwest Planning Service for open lots is 7.4 kg/head/day (MWPS, 2004). In another study, as-is manure removal from an open lot ranged from 11.3 to 12.2 kg/head/day for cattle fed in summer months which is considerably higher than the estimate of Kissinger and coworkers (2006) (Luebbe et al., 2011b). In contrast Luebbe et al., (2012), reported as-is manure removal from an open lot from cattle fed over the winter was lower than estimates of Kissinger et al., (2006) with manure removal rates ranging 7.4 from 8.2 kg/head/day.

Nutrient characteristics of manure were estimated based on animal excretion (Figure 1.2; MWPS, 2004; ASAE, 2005). These values can be considered the theoretical maximum manure nutrients that could be captured by a system and do not take into consideration environmental losses of manure nutrients post-excretion in a typical feedlot setting. Additionally, it is important to note that both references ASAE and MWPS were published in the mid-2000s and therefore do not represent diets with high inclusion rates of co-products that have since become popular in the Upper Midwest.

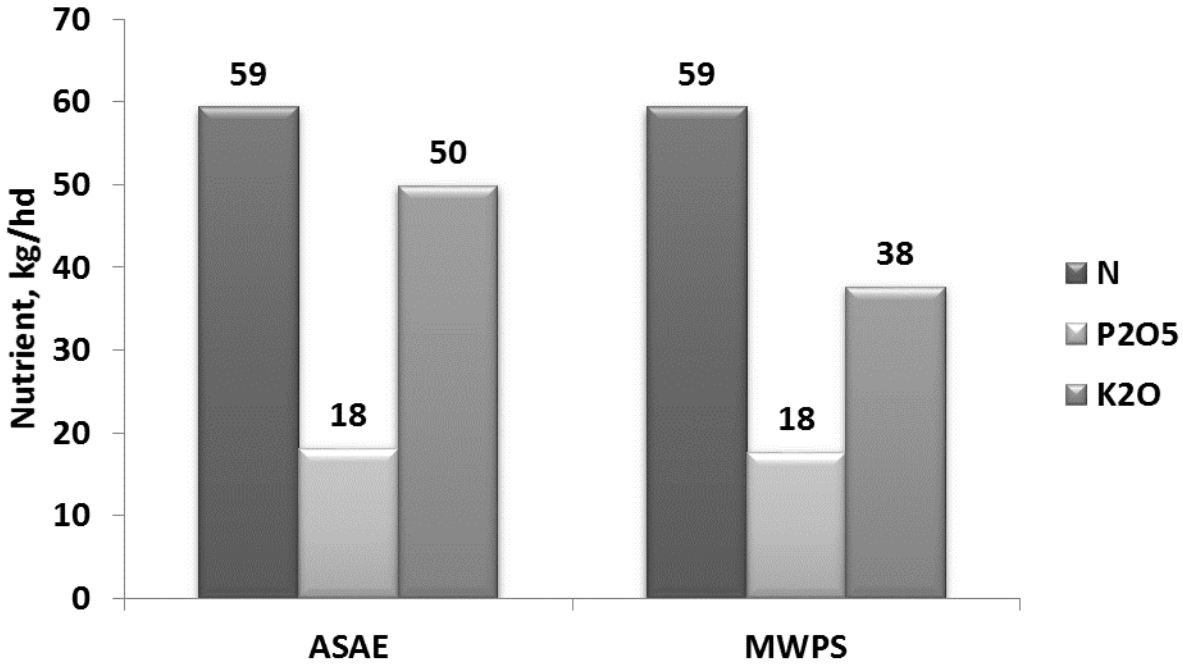

Figure 1.2 Estimates of manure nutrient yield derived from commonly accessed publications

Nutritional strategies to alter manure nutrients

Dietary interventions have been explored as a management strategy to influence manure nutrient output. Largely, focus has been on strategies to decrease NH_3 emissions through a reduction in urinary N output (Erickson and Klopfenstein, 2001). The majority

of NH_3 emitted from cattle feedlots and other concentrated animal feeding operations is a result of microbial hydrolysis of urinary urea to ammonium and carbon dioxide (Cole et al., 2005). As N intake increased a concomitant increase in urinary urea N was typically observed (Cecava and Hancock, 1994; James et al., 1999; Cole et al., 2005). Increasing dietary CP concentration from 11.5 to 13% resulted in greater urinary N and urea-N, resulting in NH_3 emission 60 to 200% greater (Cole et al., 2005). Similar results have been observed in dairy heifers; a 28.1% increase in NH_3 emissions was observed through an increase in dietary CP from 9.6 to 11.0 %, which was accompanied with increases in urea N, total, N and the percentage of N excreted in the urine (James et al., 1999). Regardless of basal CP concentration, increasing RDP as a percent of CP increased urinary N and urinary urea-N concentrations while decreasing fecal N concentration (Cole et al., 2005). Similarly, supplementation of barley-based backgrounding diets containing 12% CP with NPN alone or in combination RDP and RUP to attain 14% CP did not impact fecal N output, but increased urinary N and urinary urea-N irrespective of protein source (Koenig and Beauchemin, 2013). Increased intake of rumen degradable N increases NH_3 concentration in the rumen, which in turn decreases urea recycling to the rumen, ultimately resulting in greater urinary urea output (Huntington and Archibeque, 2000).

Although decreasing CP in order to reduce NH_3 emissions was efficacious, there is a balance between N intake and animal performance, with reductions in ADG and feed efficiency observed with decreased N intake (Gleghorn et al., 2004; Archibeque et al., 2007a). Recognizing that N retention and maximum performance was achieved in a

previous study for cattle fed between 11.5 and 13% CP (Gleghorn et al., 2004), Cole and coworkers (2005) hypothesized that phase feeding CP through finishing may decrease NH_3 emissions without negatively impacting cattle performance. This hypothesis is supported by a comparison of feeding yearling and calf-fed steers using the NRC (1996) MP system. Matching protein provision to biological requirement and thereby decreasing protein provision across the feeding period, compared to feeding 13.5% CP across the feeding period. Across the entire finishing period N excretion was decreased in yearlings and calf-feds by 10 to 20% without compromising animal performance (Erickson and Klopfenstein, 2001). Manure N did not differ between protein feeding strategies, suggesting that when protein is phase-fed, requirements were met but not exceeded and less urinary N was excreted.

As another alternative to provision of a constant concentration of CP across a finishing period, oscillating dietary CP in short intervals, typically 48-hour intervals, has been explored in both sheep and cattle to maximize protein utilization without exceeding requirements and thereby decreasing N excretion (Cole, 1999; Archibeque et al., 2007b; Doranalli et al., 2011). An increase in N recycling to the rumen is theorized to increase microbial activity and growth and therefore protein fermentation and AA availability with oscillation of protein provision (Cole et al., 2003; Archibeque et al., 200ba). Doranalli et al., (2011) observed increased urea flux across the rumen epithelium in lambs fed oscillating dietary CP concentrations on a 48-hour basis during periods when animals were consuming the low-CP diet. Oscillating protein provision (2 days at 11.9% and 2 days at 14.9% CP) resulted in similar N intake to medium protein provision

(11.9%) and decreased N intake compared to high protein provision (14.9%) (Archibeque et al., 2007a). Fecal N, urinary N, and urinary urea-N output were lower for the medium and oscillating treatments but the feeding oscillating or high CP treatment resulted in greater N digestibility and feeding oscillating treatment led to greater retained N compared to that observed with the high CP treatment. Following an 11-day in vitro incubation, nitrate- and nitrite-N emissions were lower for the oscillating and medium protein provision treatments as compared to the high treatment. In contrast, increased nitrate-N concentrations were observed following a 35-day incubation of manure slurries with high (14.9% CP) and oscillating (2 days at 11.9% and 2 days at 14.9% CP) treatments, as compared to low (9.1% CP) and medium (11.9% CP) treatments (Archibeque et al., 2007a). This is possibly a function of greater rumen protein degradation for oscillating and high CP treatments; however, effects on animal performance were only observed for the low CP treatment. Feeding low CP led to reduced ADG and poorer feed efficiency, as compared to those observed for the medium, high and oscillating treatments, suggesting that the most advantageous balance of animal performance and N emissions was achieved at 11.9% CP.

Site of carbohydrate digestion impacts route of N output, with increased hindgut fermentation resulting in increased fecal N at the expense of urinary N excretion (Ulyatt et al., 1975). Results from a study in which pectin was infused into the abomasum in dairy cattle demonstrated that increasing hindgut carbohydrate fermentation has the potential to decrease ruminal NH_3 concentrations (Gressley and Armentano, 2005). Shifting fermentation to the hindgut likely reduces ruminal NH_3 concentrations through a

shift in the urea cycle, with the hindgut acting as an alternate sink for urea (Hall and Huntington, 2008).

Increasing diet NDF in diets with similar concentrations of CP and RDP, through inclusion of wet corn gluten feed, increased fecal N and OM while decreasing urinary urea-n output (Bierman et al., 1999). Reductions in diet OM digestibility, through inclusion of corn bran, with and without corn steep, as compared to a control dry rolled corn diet increased fecal OM and N excretion; however, N loss was only impacted during winter months leading the authors to postulate that pen surface OM impact on N loss was dependent on environmental conditions (Sayer et al., 2013). In contrast, inclusion of alkaline-treated corn stover in diets containing 40% modified distillers grains with solubles increased pen surface OM without altering N loss during winter or summer feeding periods (Johnson et al., 2015).

Inconsistencies observed in the impact of changing diet OM digestibility is likely due to the complexity of urea cycle regulation. Decreasing diet OM digestibility through higher inclusion of high NDF ingredients increases hindgut fermentation, which is expected to decrease ruminal NH_3 concentrations and therefore increase urea recycling while reducing urea clearance through urine. However, diets high in rapidly fermentable carbohydrates increase rumen bacterial cell production efficiency (Henning et al., 1991) and therefore have greater capacity to assimilate the products of fermentation, thus requiring greater N (Huntington and Archibeque, 2000). This assertion is supported by observations that increasing diet OM digestibility increases the rate of endogenous urea transfer from the blood to the lumen of the gastrointestinal tract (Kennedy and Milligan,

1980). Further consideration must be given to whole body N metabolism. In high-producing animals, tissue synthesis may act as a N sink, reducing ureagenesis beyond what would be expected on a high protein diet (NRC 1985).

Increased awareness of the environmental impact of P excretion from beef feedlots encouraged a re-evaluation of the P requirement of growing and finishing cattle. The Nutrient Requirements of Beef Cattle (1996) estimates the maintenance P requirement to be 16 mg of absorbed P/kg of BW and the requirement for gain as 3.9 g absorbed P per 100 g retained protein. However, there are a number of studies suggesting the P requirement for finishing cattle is overestimated (Erickson et al., 1999; Erickson et al., 2002; Geisert et al., 2010). Yearling steers receiving a grain-based diet containing 0.14, 0.19, 0.24, 0.29 or 0.34 P as a percentage of DM had similar growth performance, carcass characteristics, or ossification of bone tissue (Erickson et al., 1999). Thus, Erickson and coworkers (1999) suggested that P requirements for yearling steers fall below 15.9 g/d (0.14% of DM) as compared to the 22.5 g/d P (0.20% of DM) recommended by the Nutrient Requirements of Beef Cattle (1996). Similarly, the P requirement for calf-fed steers was found to be less than 14.2 g/d (0.16% of DM) while the Nutrient Requirements of Beef Cattle (1996) estimated a requirement of 19 g/d (0.22% of DM; Erickson et al., 2002). In a study evaluating the P requirements of heifers, the Nutrient Requirements of Beef Cattle (1996) suggested the P requirement was 21 g P/day; in contrast, results from a different suggested that 14.1 g/d (0.17% of DM) was sufficient (Geisert et al., 2010). Geisert et al., (2010) detected no differences in plasma P for heifers fed 0.17, 0.24, 0.31, 0.38% P, but observed plasma P concentrations indicative

(< 4.5 mg/dL) of P deficiency in heifers fed 0.10% P. Overestimation of P requirements by the Nutrient Requirements of Beef Cattle (1996) may be due to the assumption of equal P availability across all sources, or incorrect estimations of maintenance or growth requirements (Block et al., 2004).

The maintenance and growth requirement equations developed by the Nutrient Requirements of Beef Cattle (1996) are based on absorbed P; however, a single absorption coefficient of 68% was assumed for all sources of P. Recommendations for dairy cattle recognize that feed and mineral sources vary in availability (Table 1.1; NRC, 2001). Phosphorus availability coefficients range from 0.35 to 0.95 for forages, from 0.38 to 0.98 for concentrates, and from 0.29 to 1.00 for byproducts (Sehested and Weisbjerg, 2002). It appears necessary to make use of P absorption coefficients specific to the feed or mineral source in question in order to improve P requirement recommendations, although it is unlikely that the imprecise use of absorption coefficients alone explain the difference between observed P requirements and Nutrient Requirements of Beef Cattle (1996) recommendations.

Table 1.1. Phosphorus absorption coefficients for mineral sources[a]

Item	Phosphorus absorption coefficient
Ammonium phosphate (dibasic), $(NH_4)_2HPO_4$	0.80
Ammonium phosphate (monobasic), $NH_4H_2PO_4$	0.80
Dicalcium phosphate (dibasic), $CaHPO_4$	0.85
Phosphate	0.65
Sodium phosphate (monobasic) monohydrate, $NaH_2PO_4 \bullet H_2O$	0.90
Sodium tripolyphosphate (meta and pyrophosphate, $Na_5P_3O_{10}$	0.75

[a]Adapted from the Nutrient Requirements of Dairy Cattle (2001)

Phosphorus maintenance requirements are based on the endogenous loss of P measured in feces when cattle are fed at or near requirements; however, there is some evidence that P excretion shifts to urine in high-concentrate diets (Scott and Buchan, 1985). Additionally, the equation fails to take into full consideration the role of salivary production in endogenous P loss. Salivary P makes up the majority of endogenous P losses, although a small portion can be attributed to the sloughing of tissues into the digestive tract (Karn, 2001). Saliva production is influenced by eating and ruminating, as well as the physical nature of the diet, with both the level of forage and concentration of effective NDF influencing saliva production (Pitt et al., 1996). The data used by the Nutrient Requirements of Beef Cattle (1996) for determination of the P requirement was based on several studies from the 1950s and 1980s. Feedstuffs utilized in those studies differ from those found in a typical feedlot diet today and included higher levels of roughage. Combined, these factors have the potential to affect saliva production and potentially generated greater endogenous P loss estimates than would be observed with modern diets. It has been suggested that including saliva production, as a function of DMI and effective NDF, would improve precision of P maintenance recommendations (Block et al., 2004) .

Nutrient Requirements of Beef Cattle (1996) recommendation of P requirements for growth were developed using body composition data from dairy cattle published by Ellenberger and coworkers (1950). This method makes the assumption that there is a constant relationship between protein gain and P retention. Bone contains 80 to 90% of body P, while 60 to 85% of protein is found in soft tissue (Ellenberger et al., 1950). The

lean-to-bone ratio in dairy cattle is < 3.4 while common beef breeds typically have lean:bone ratios of 3.6 to 4.0, which suggests that the relationship between protein gain and P retention may be differ by breed (Kempster et al., 1982). Additionally, nutritional management would be expected to alter the relationship between protein gain and P retention in scenarios where cattle are maintained on a lower plane of nutrition during the growing phase and enter the feedlot with greater skeletal maturity. This is supported by results from the Nebraska trials, which demonstrated P requirements of yearlings to be lower than that of calf-feds, 0.14% of DM and 0.16% of DM, respectively (Erickson et al., 1999; Erickson et al., 2002). Block et al., (2004) proposed that P retention estimates would be improved by accounting for both skeletal growth and mineralization and soft tissue gain. Furthermore, based on P recommendations for swine (NRC, 1998), which differentiate between P required to optimize animal growth and P required for maximum skeletal mineralization, it is possible that the P requirement for cattle growth may be lower than P retention.

The latest edition of the Nutrient Requirements of Beef Cattle (2016) recognizes that the P requirement of previous editions overestimates animal requirements but does not define a lower requirement. Although clarification of the P requirement for finishing cattle is valuable from the standpoint that it is expected to discourage provision of supplemental P, P in typical high-concentrate finishing diets exceeds P requirements due to the P contribution from basal ingredients alone. Cereal grains contain 0.25 to 0.30% P on a DM basis while co-products such as corn gluten feed and distillers contain 0.95 to 1.40% P (NRC, 1996). Discontinuing the practice of including supplemental P sources in

feedlot diets will minimize the impact of excess P in the environment; however, identifying alternative methods for handling manure nutrients may be necessary in the long run for the environmental sustainability of feedlots.

Feedstuff selection is integral in minimizing manure nutrient loss; however, this goal is often challenging to achieve without increasing cost of gain through either increased ration costs or sacrifices in animal performance. For example, inclusion of distillers grains plus solubles in feedlot diets is ubiquitous across the Midwest due to widespread availability, a nutrient profile that lends itself towards use as a protein or energy source and improvements in performance relative to corn-based diets. The nutrient profile of distillers grains plus solubles, when used as an energy source in finishing diets, exceeds recommendations for dietary protein, N and P (Klopfenstein et al., 2008). Linear increases in both N and P intake and excretion were observed when feeding WDGS at 15 and 30 % DM of the finishing ration, as compared to a corn control diet (Luebbe et al., 2012). Although total N excretion increased with increasing WDGS inclusion, no difference in NH_3 volatilization was observed. The authors postulated that this may be a function of a decrease in OM digestibility, as compared to the control, which increased post-ruminal fermentation and shifted urine N excretion to fecal excretion. This hypothesis is supported by observations of a linear decrease OM digestibility with WDGS solubles inclusions of 15, 30, 45 and 60% (DM basis; Luebbe et al., 2012); although, other researchers have not observed differences in OM digestibility of WDGS fed at lower inclusion rates (15%, DM basis; May et al., 2010). Inclusion of WDGS at 20, 40 and 60% DM also linearly increased N and P intake and excretion,

relative to a dry rolled corn control diet (Spiehs and Varel, 2009). Spiehs and Varel (2009) found that increased total N excretion was due to a linear increase in urinary N excretion. Similar trends have been observed when feeding other co-products. Inclusion of wet corn gluten feed at 35% DM increased N intake, N excretion and N lost to NH_3 volatization (Farran et al., 2006).

Management strategies to alter manure nutrients

The largest proportion of N loss in open lots occurs from N volatization from the feedlot surface, which is primarily a function of the hydrolysis of urea to CO_2 and NH_3 by ureases. Urease inhibitors decrease N volatization (Varel et al., 1999; Parker et al., 2005). Cyclohexylphosphoric triamide and N-(n-butyl) thiophosphoric triamide reduce the rate of urea hydrolysis in beef cattle open feedlot pens for a short duration following application (Varel et al., 1999). Urea accumulation in dry manure peaked 4 to 9 days following application and disappeared by 11 days post-application of Cyclohexylphosphoric triamide and N-(n-butyl) thiophosphoric triamide, respectively; however, weekly application of N-(n-butyl) thiophosphoric triamide limited urea volatilization (Varel et al., 1999). Similarly, N-(n-butyl) thiophosphoric triamide application in a simulated open feedlot model, using an *in vitro* approach, was most effective at reducing NH_3 emission when applied in 8-day intervals, compared to 16- or 31-day intervals (Parker et al., 2005). Parker and coworkers (2005) noted that urease inhibitor application would likely need to increase in frequency or concentration with increased cattle days on feed to account for greater urea accumulation on the pen surface.

Primary manure removal from open lot feedlots occurs on an annual basis, shortly before manure spreading on cropland, or when animals are marketed and the pen is prepared for a new set of incoming cattle; however, frequent removal of manure from around feed and watering areas is a common management practice. The resulting pen scrapings are then stored until manure application to crop ground. Storage type and management alter manure nutrient loss prior to field application (Eghball et al., 1997; Hao et al., 2004; Parkinson et al., 2004; Larney et al., 2006; Luebbe et al., 2011a). Composting, a controlled aerobic decomposition, and stockpiling, anaerobic decomposition, are the primary manure storage strategies. Nitrogen volatization is the primary concern during manure storage; however, additional N may be lost through runoff or nitrate leaching during storage, with the relative quantities of N loss through these processes being highly dependent on site-specific conditions (Eghball et al., 1997). Furthermore, runoff of P may also be expected to follow the same pattern as N runoff during storage.

Total N loss ranged from 19 to 42% during windrow composting, without addition of a C source, and was closely related to the initial manure N content such that windrows with greater initial N had higher N loss during composting (Eghball et al., 1997). The primary route of N loss during composting was NH_3 volatization, accounting for greater than 91% of N loss, with runoff of nitrate and ammonium only accounting for less than 0.5% of total N loss (Eghball et al., 1997). Nitrogen loss of compost from pens utilizing bedding were dependent on the bedding source utilized, windrow composting of straw-bedded manure resulted in 41.6% loss of total N compared to 11.8 % total N loss of

wood chip-bedded manure (Hao et al., 2004). Nutrient losses from composting are highly dependent on management, with increased turning frequency and turning early after pile formation both contributing to increased N loss through leaching and gas release, in the forms of NH_3 and NO_2 (Parkinson et al., 2004). In a comparison of stockpiling and composting, N loss was observed to be 29.3 and 42.1% greater with windrow composting in two experiments (Luebbe et al., 2011a). Total mass loss did not differ between strategies and C loss was inconsistent across experiments, with increased C loss observed in Experiment 1 for the composting treatment but no difference between treatments observed in Experiment 2. Similarly, increased N loss was observed with composting compared to stockpiling (46.3 vs 22.5%) and increased C loss was observed with composting (Larney et al., 2006). Phosphorus loss during windrow composting was measured at 0.8 to 2.2% of initial manure P (Eghball et al., 1997). Greater P losses were observed in a comparison of stack composting and stockpiling, with P loss, as a percentage of initial P, measured at 28.2 and 27.4% in compost stacks turned once or three times, respectively, compared to 11.8% for stockpiled manure (Parkinson et al., 2004).

Chapter 2. Modeling nutrient requirements of heavy weight steers at the end of the finishing period

Summary

Improvements in genetics, nutritional strategies, and management, combined with the use of growth promoting agents have resulted in heavier carcass weights. Animal nutrient requirements are dynamic and the ability to accurately predict the requirements of modern, heavy cattle based on historic data has not been explored. A dataset derived from 19 studies containing 289 means for treatments testing ractopamine during the final 14 to 42 days of finishing was subjected to a meta-analysis to develop a regression equation (Heavy Model; HM) describing energy requirements of heavy weight steers at the end of finishing. A validation dataset derived from 13 studies containing 41 means for treatments testing zilpaterol during the final 21 to 35 days of finishing was used to validate the regression equation generated by the HM and the Nutrient Requirements of Beef Cattle (NRC; 2016) energy equation in a group of heavy weight steers. The equation developed from the test dataset for the HM is RE = (68.82*EBG)-(3.68*EBG^2)*$EQEBW^{0.75}$/1000. Predicted RE of cattle in the validation dataset did not differ from observed RE for the NRC (P = 0.65) or HM (P = 0.49). The NRC model explained 78% of the variation in RE, with a 1.11% over-prediction bias and the HM explained 88% of the variation in RE, with a 0.27% under-prediction bias. Compared with the NRC model, utilization of the HM to predict energy requirements in heavy weight steers at the end of finishing explains a greater portion of the variation in observed versus predicted RE with a lower bias.

Introduction

Improvements in genetics, nutritional strategies, and management, combined with the use of growth promoting agents have resulted in heavier carcass weights. The magnitude in year over year carcass weight changes is largely driven by industry economics, specifically cattle supply and feed prices; however, the long-term trend has been toward harvesting cattle at heavier weights. Annual average carcass weights for steers, on a dressed basis, were 25% higher in 2016 compared to 1974 (USDA, 2017). Additionally, cattle feeders in the Upper Midwest have traditionally finished cattle at heavier weights relative to cattle finished in the Great Plains. Although there has been a long-term trend toward finishing cattle at heavier weights, diets continue to be formulated based on nutrient requirements derived from lighter cattle and extrapolated out to heavier weights. Animal nutrient requirements are dynamic and the ability to accurately predict the requirements of modern, heavy cattle based on historic data has not been explored. The objective of this study was to model energy requirements of heavy weight steers at the end of the finishing period.

Materials and Methods

Test dataset

A dataset derived from 19 studies containing 289 means for treatments testing ractopamine during the final 14 to 42 days of finishing was subjected to a meta-analysis to develop regression equations describing energy requirements of heavy weight cattle at the end of finishing.

Daily heat production (HP) was determined by difference (metabolizable energy intake [MEI], mcal/day – retained energy [RE], mcal/day) and the log of daily HP kcal/

kg body weight $(BW)^{0.75}$ was regressed on MEI/ kg $BW^{0.75}$ to determine fasting HP in order to evaluate maintenance requirements. Fasting HP is defined as HP at zero MEI. A logarithmic equation was used to describe this relationship because extrapolation to zero energy intake results in a more realistic estimate of fasting HP (Lofgreen and Garrett, 1968). Energy requirements were developed using only the treatment means of steers (216 treatment means). Analysis of heifer and Holstein requirements were omitted due to insufficient animal numbers to generate meaningful conclusions.

A ratio of observed to expected dry matter intake (DMI) was used to determine a correction multiplier to account for the variability in DMI attributed to differences in management and environment across experiments (Zinn et al., 2008).

Final shrunk body weight (FSBW) was adjusted for implant strategy and beta adrenergic agonist (β-AA) use within the range recommended by the Nutrient Requirements of Beef Cattle (2016). An adjustment of -35, 0, or 35 kg was made to FSBW for use of no implant, estrogen implant, or estrogen/TBA combination implant, respectively. Final shrunk body weight was adjusted by 0, 10, or 14 kg for use of no β-AA, ractopamine, or zilpaterol, respectively. Dietary metabolizable energy (ME) was increased by 2.3% for cattle fed monensin and daily feed required for maintenance multiplied by a factor of 1.0 or 0.9 for *Bos taurus* and *Bos indicus*, respectively, to reflect breed impact on maintenance requirements (NRC, 2016). The ME required for maintenance was calculated by iteration, assuming that the maintenance requirement is 77 kcal per kg $BW^{0.75}$ (Lofgreen and Garrett, 1968), with the remaining feed designated as feed available for gain. Feed available for gain and feedstuff NEg were used to

calculate RE and a regression approach was used to generate new RE requirement equations. The dependent variable is RE kcal/equivalent empty body weight $(EQEBW)^{0.75}$ kg and independent variables are empty body gain (EBG), kg and EBG^2, kg.

Validation dataset

A dataset derived from 13 studies containing 41 means for treatments testing zilpaterol during the final 21 to 35 days of finishing was used to validate regression equations describing energy requirements of heavy weight steers at the end of finishing. Retained energy was calculated using the Nutrient Requirements of Beef Cattle (2016) equation ($RE = 0.0635 * EQEBW^{0.75} * EBG^{1.097}$) or equation developed from the test dataset (Heavy Model [HM]; $RE = (68.82*EBG)-(3.68*EBG^2)*EQEBW^{0.75}/1000$).

Final shrunk body weight was adjusted for implant strategy and β-AA use within the range recommended by the Nutrient Requirements of Beef Cattle (2016). Final shrunk body weight was adjusted by -35, 0, or 35 kg for use of no implant, estrogen implant, or estrogen/TBA combination implant, respectively. Final shrunk body weight was adjusted by 0. 10, or 14 kg for use of no β-AA, ractopamine, or zilpaterol, respectively. Dietary ME was increased by 2.3% for cattle fed monensin and daily feed required for maintenance multiplied by a factor of 1.0 or 0.9 for *Bos taurus* and *Bos indicus*, respectively, to reflect breed impact on maintenance requirements (NRC, 2016).

Outliers were identified using the plot of studentized residue against the predicted values and removed when points fell outside the range of -2.5 to 2.5.

Data transformations

A number of conversions were required to transform data to units appropriate for use in existing equations and eliminate effect of body size on requirements.

- EBW=0.891 * SBW, where EBW is empty body weight and SBW is shrunk body weight
- EBG = 0.956 * SWG, where EBG is empty body gain and SWG is shrunk weight gain
- SRW = 478 kg for animals finishing at small marbling (28% body fat), where SRW is shrunk reference weight
- EQSBW = SBW * (SRW/FSBW), where EQSBW is equivalent shrunk body weight and FSBW is final shrunk body weight
- EQEBW = 0.891 * EQSBW, where EQEBW is equivalent empty body weight

Data analysis

Data were analyzed using the Mixed Procedure of SAS 9.3 (SAS Institute Inc., Cary, NC). The experimental unit in both the test and validation datasets was either a pen of cattle or an individual animal depending on the experimental unit reported in each study. Treatment means were weighted by the experimental unit/mean in order to account for varying number of cattle per pen or individuals per treatment. Statistical significance was characterized at $\alpha < 0.05$ and a tendency for significance at $0.05 < \alpha < 0.10$.

Test dataset

The Means procedure of SAS was used to summarize the model development dataset, heifers and Holsteins were excluded from analysis. Variables included average daily gain, DMI, feed efficiency, initial body weight, final body weight, and days on feed.

Mean, minimum, maximum, range, and standard deviation were generated for each variable. Beta-agonist was considered a class variable.

The GLM procedure of SAS was used to perform a regression analysis, where the log of HP was regressed on MEI. The comparison of intercepts between sexes was accomplished through use of the SOLUTION statement.

The GLM procedure of SAS was used to perform a regression analysis, where kcal of RE per kg of $EQEBW^{0.75}$ was the dependent variable and EBG and EBG^2 were the independent variables (HM). Individual trial and treatment within trial were considered class variables. The NOINT option was utilized to omit the intercept term from the model.

Model validation

Predicted RE from the NRC (2016) and HM were regressed on observed RE from the validation dataset. An F-Test was conducted to test the null hypothesis that predicted RE for each model did not differ from observed RE. The alternative hypothesis was that predicted RE differed from observed RE. Results were considered significant with $P < 0.05$. Bias was calculated as the percentage deviation of the slope from a theoretical value of 1.0 when predicted RE was regressed on actual RE with a zero-intercept model.

Results

Weighted means for feedlot performance characteristics of steers in the test dataset are shown in Table 2.1.

Table 2.1. Weighted means for feedlot performance characteristics of test dataset

	No beta-agonist				Beta-agonist			
	Average	S. D.	Min	Max	Average	S. D.	Min	Max
Treatment means	78				138			
Animals	15,528				27,857			
Shrunk initial weight, kg	532	93	424	603	534	96	419	605
Shrunk final weight, kg	578	101	477	668	586	101	487	680
DMI, kg	10.16	4.54	6.85	14.15	10.02	3.86	6.67	14.51
ADG, kg	1.42	0.86	0.69	2.10	1.62	0.86	0.79	2.59
Gain to feed	0.132	0.263	0.189	0.075	0.156	0.417	0.250	0.112

The regression of daily heat produced (kcal/$BW^{0.75}$ kg) on MEI (kcal/$BW^{0.75}$ kg) yield y-intercepts of 1.9276 and 1.9208 for heifers and steers, respectively (Figure 2.1, Figure 2.2). The inverse log transformation yields estimates of daily HP of 84.65 and 83.18 kcal/$BW^{0.75}$ for heifers and steers, respectively. Gender was not statistically significant in the model for fasting HP ($P = 0.49$). Combined regression of log of HP on MEI yielded a y-intercept of 1.9207 which results in a value of 83.17 kcal/$BW^{0.75}$ for fasting HP of steers and heifers.

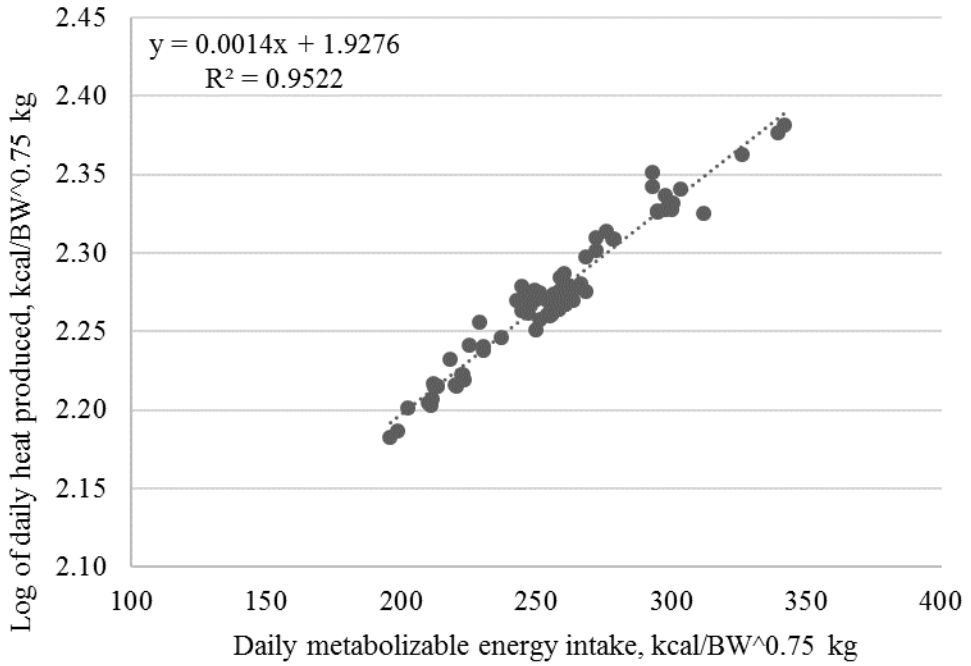

Figure 2.1. Determination of fasting heat production of test dataset heifers. Each point represents a treatment mean, with a total of 45 treatment means representing 7,884 head.

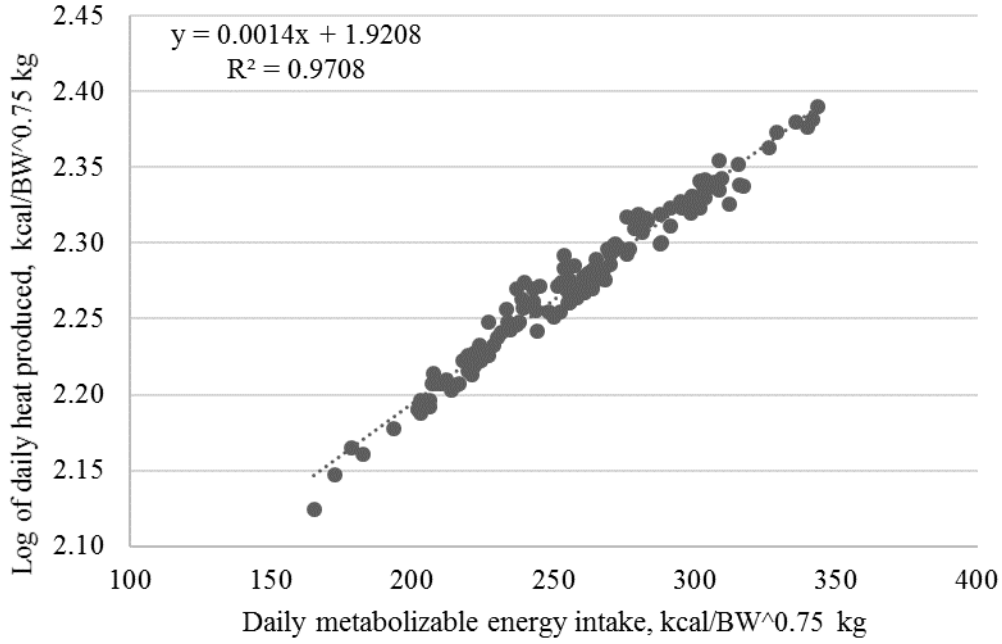

Figure 2.2. Determination of fasting production of test dataset steers. Each point represents a treatment mean, with a total of 153 treatment means, representing 29,827 steers

The equation developed from the test dataset for the HM is RE = (68.82*EBG)-(3.68*EBG^2)*EQEBW$^{0.75}$/1000. Daily RE was predicted from the NRC and HM equations and compared to observe RE from the validation dataset (Table 2.2) Data is also presented as the ratio of observed to predicted RE for the NRC and HM model in Figure 2.3. Three observations were identified as outliers and removed from the validation model dataset.

Table 2.2. Observed and predicted daily retained energy of feedlot steers

	Daily Retained Energy, mcal		
Observation	Observed	NRC (2016) Predicted	HM Predicted
1	7.73	8.04	7.94
2	7.57	8.67	8.42
3	8.20	6.16	7.39
4	7.36	6.09	7.21
5	11.88	11.32	11.13
6	11.63	10.95	10.78
7	7.68	7.96	7.85
8	8.94	9.82	9.54
9	8.08	7.94	7.88
10	6.82	8.50	7.79
11	6.13	8.01	7.64
12	5.64	6.36	6.23
13	5.67	6.36	6.24
14	5.58	6.43	6.30
15	5.47	6.87	6.66
16	5.51	6.89	6.67
17	5.41	6.69	6.49
18	9.27	8.50	8.37
19	8.82	8.99	8.71
20	8.30	8.17	8.10
21	7.92	7.88	7.82
22	7.74	8.15	8.02
23	7.49	7.92	7.80
24	7.48	6.49	6.58
25	7.43	6.35	6.53

26	6.73	5.70	5.89
27	6.80	6.52	6.56
28	6.78	6.42	6.51
29	5.71	5.30	5.44
30	7.56	6.57	6.72
31	6.49	6.12	6.23
32	10.65	10.03	9.95
33	10.74	10.78	10.50
34	9.94	10.30	10.03
35	9.92	10.36	10.10
36	10.77	11.19	10.89
37	11.25	10.92	10.52
38	9.88	9.86	9.68
	F value	0.43	0.73
	P value	0.65	0.49
	R^2	0.79	0.88
	Bias, %	1.11	-0.27

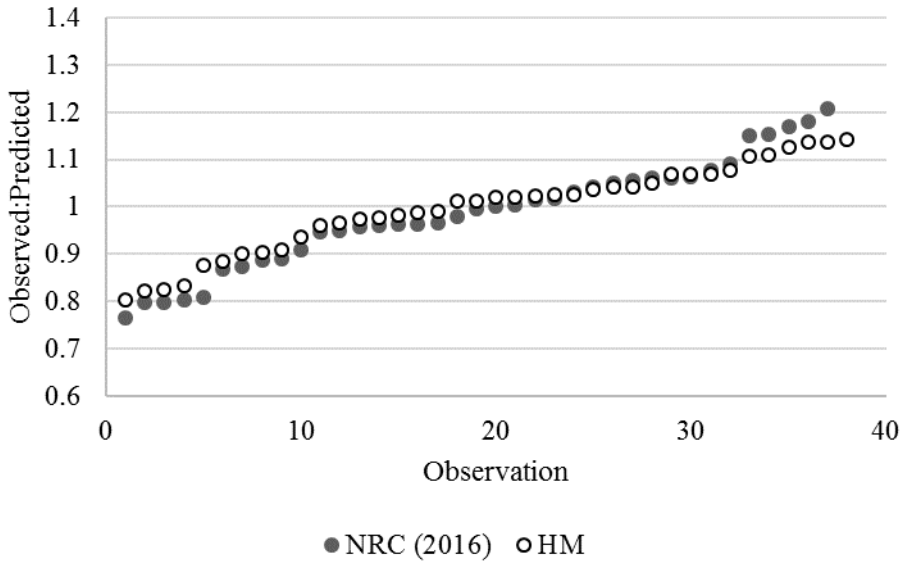

Figure 2.3. Observed to predicted daily retained energy, Mcal

Predicted RE did not differ from observed RE for the NRC (P = 0.65) or HM (P = 0.49). The NRC model explained 78% of the variation in RE, with a 1.11% over-prediction bias and the HM explained 88% of the variation in RE, with a 0.27% under-prediction bias.

Discussion

Maintenance requirements can be estimated by regressing daily HP on daily MEI, with HP at zero MEI representing the requirement for maintenance. Regressions for heifers and steers yielded estimates of daily HP of 84.65 and 83.18 kcal/$BW^{0.75}$, respectively. A comparison of the intercepts of the steer and heifer equations was not significant, with the combined regression yielding a daily HP estimate of 83.17 enter units. These values are higher than that of the classical maintenance requirement and slightly higher than the range of HP calculated for the group of cattle used to determine the classical maintenance requirement (Lofgreen and Garrett, 1968). The range of HP of fasted cattle was determined to lie between 72 and 82 kcal per $W^{0.75}$, with the mean value of 77 kcal per $W^{0.75}$ adopted as the maintenance requirement. Maintenance requirements for steers and heifers did not differ, which is consistent with Lofgreen and Garrett (1968) and other researchers (Garrett, 1970; Garrett, 1980; Chizzotti, 2007). Determining the factors that increase the maintenance requirements of the cattle in the dataset, relative to the classical equation, are outside of the scope of this study and therefore they are implicitly incorporated into the NEg requirement in order to maintain consistency in energy values of feedstuffs.

The basic premises of the California Net Energy System (CNES) dictate that if the energy concentration and DMI of a diet is known then performance can be predicted. The opposite is also true, if performance and DMI are known then energy concentration can be predicted. When this premise does not hold true it suggests a portion of the system is compromised (Zinn et al., 2008). The Nutrient Requirements of Beef Cattle (NRC, 2016) and HM were used to predict RE at the end of finishing in steers and the output of each model was compared to observed performance (Table 2.2). Predicted RE did not differ from observed RE for the NRC (P = 0.65) or HM (P = 0.49), suggesting that both models are appropriate to predict energy requirements of heavy weight cattle at the end of finishing. The ratio of observed to predicted RE for each model is shown in Figure 2.3. If the models were predicting animal performance with 100% accuracy the ratio of observed to predicted RE would be 1. Observed to predicted RE ratio ranged from 0.77 to 1.33 for the NRC model and 0.80 to 1.14 for the HM. The NRC model explained 79% of the variation in RE, with a 1.11% over-prediction bias and the HM explained 88% of the variation in RE, with a 0.27% under-prediction bias.

The CNES was a major accomplishment in advancing feedlot nutrition as it provided an empirical model to explain the complex biological system of growth and maintenance in cattle that was easily applied in production settings; however, it is not without some criticisms. A frustration for cattle feeders and nutritional consultants alike is found in the challenge of explaining deviations of animal performance compared to predicted performance derived from energy intake. In part, these deviations from predicted performance lie in the oversimplification of complex biological systems into an

empirical model. Over time, a number of adjustments have been made to the original CNES model in order allow for its application to modern production systems. These adjustments allow for factors such as breed and nutritional technologies to be incorporated into the model. The current CNES model does not account for potential differences in BW that are a function of differences in physiology. The HM recognizes that modern-type heavy weight cattle, and consequently their genetic potential for performance at heavier weights and a greater degree of physiological maturity, were not included in the data used to derive previous equations. The equations derived from a cohort of heavy cattle would not apply to those same cattle at lighter weights; however, application of the proposed HM equations explains a greater proportion of the variation in RE at the end of finishing and may have a place in precision feeding of cattle at heavier weights. Further improvements in elucidating the energy requirements of heavy weight steers at the end of finishing could be accomplished through direct measurement of RE through the use of comparative slaughter techniques; however, this is a time and cost intensive approach. Post hoc analysis, such as conducted in this study, presents challenges but allows for evaluation of nutrient requirements that can be tailored to a number of production scenarios. The greatest challenge in the development of the current model is limited available information on past management and nutritional management, an attempt was made to correct for these differences in adjusting DMI (Zinn et al., 2008) to account for differences in management and environment between experiments. Ultimately, utilization of the HM to predict energy requirements in heavy weight steers at

the end of finishing explains a greater portion of the variation in observed versus predicted RE with a lower bias.

Chapter 3. Measuring feedlot manure nutrient output

Summary

Volatility in fertilizer prices have generated interest in capturing value through manure in integrated crop and cattle feeding systems. The impact of facility design (Open lot, Pack, Stockpile, Pit, Lagoon), cattle type (Beef or Holstein), and dietary energy value (Grower or Finisher) on manure nutrient concentration was measured. Manure nutrients were expressed as kg nitrogen (N), phosphate (P_2O_5), or potash (K_2O)/tonne of as-is solid material or as kg/3,785 L liquid material. Projected annual manure production values of 2.7 and 4.5 tonne/head and 9,463 L/head, respectively, for Open lot, Pack and Pit, were utilized to project effects of facility on yearly manure nutrient contributions per head space. Nutrient concentrations of liquid manure samples from Pit was greater ($P < 0.05$) than that from Lagoon across all nutrients. Nitrogen concentrations of liquid samples was greater ($P < 0.05$) for Holstein, and P_2O_5 tended to be greater ($P < 0.10$) for Holstein. Nitrogen in solid samples was not impacted by facility type ($P > 0.10$); however, P_2O_5 concentrations were lower ($P < 0.05$) in Pack compared to Open lot and Stockpile. Concentrations of nutrients in solid manure samples were greater ($P < 0.05$) for Beef as compared to Holstein. Dietary energy value did not impact ($P > 0.10$) nutrient concentrations of solid manure samples. Projected annual manure N yield per animal headspace was greatest for Pit, intermediate for Pack, and least for Open lot ($P < 0.05$). Projected manure P_2O_5 yield was greater ($P < 0.05$) for Pack and Pit facilities as compared to Open lot. These results confirm that greater manure nutrients are captured by indoor confinement feedlot facilities.

Introduction

Minimizing the environmental impact of beef production, especially that of manure produced in concentrated animal feeding operations, has been a high priority for a number of years. Previous work has focused almost exclusively on open lot feedlots (Gilbertson et al., 1971; Erickson and Klopfenstein, 2001; Cole et al., 2005), with little information available on the impact of indoor confinement feedlot designs on the nutrient profile of manure. In the Great Plains states, cattle are fed almost exclusively in open feedlots; however, in the Upper Midwest a variety of feedlot designs are implemented, ranging from open lot feedlots to intensive confinement barns of varying designs. In open lot systems, cattle are housed in a large area without provision of protection from a shed or other structure. The open lot feedlot surface may be unpaved, paved or most-commonly, a combination of unpaved surface with concrete aprons behind feeding bunks and around water troughs. The surfaces of open lots are contoured to manage runoff caused by precipitation via earthen storage basins and solid manure is removed regularly and stockpiled for later use as fertilizer. The two general types of confinement barns are deep-bedded and slatted floor over a deep pit. In both systems there are various barn configurations that are utilized, commonly including gable barns and monoslope structures. In deep-bedded barns, cattle are housed in complete confinement with a partial or total solid concrete surface. Bedding, often in the form of corn stalks, is added regularly to develop a bed-pack that provides a dry surface for cattle and is removed once or twice yearly. Slatted floor over a deep pit feedlot facilities house cattle in complete confinement with a feedlot surface consisting of concrete slats over a manure

containment pit of 2.4 to 4.3 m in depth. Although confinement feedlot facilities have existed for many years, a renewed interest in the construction of confinement facilities has been observed in recent years due to advancements in design that improve air quality and cattle comfort. Additional interest has also centered on the ability to improve manure nutrient capture through indoor confinement systems in order to remain in compliance with environmental regulations while simultaneously improving the fertilizer value of manure.

Although the perceived value of manure has increased in integrated production systems, there remain challenges in effectively utilizing manure due to its inherent variability. Environment, diet, and management have all been shown to significantly alter manure nutrient concentration (Bierman et al., 1999; Parker et al., 2005; Archibeque et al., 2007); however, little data exist on the comparative difference in manure nutrients between types of feedlots. The objective of this study is to determine the impacts of feedlot facility design, diet and cattle type on the measured nutrient value of manure produced.

Materials and Methods

Extended Ag Services, Inc. of Lakefield, MN provided a dataset containing manure nutrient value analyses with corresponding facility, diet and cattle type description from where manure was derived. Samples were collected from 2010 to 2014 from feedlots in the Upper Midwest. The dataset consisted of 689 solid sample manure nutrient analysis (as-is) results collected at open feedlots (Open lot), stockpiled manure (Stockpile) and deep bedded barns (Pack). Stockpiled manure was derived from solid

manure scrapings collected from in front of feeding and water areas on a regular basis from open lot or deep-bedded barns that were held in storage for indeterminate durations of time off the feedlot surface before utilization as fertilizer. Deep-bedded feedlots primarily consisted of monoslope structures. Manure nutrient analysis (as-is) results were available for 186 liquid samples collected from deep pits under slatted-floors (Pit) and lagoons (Lagoon). Although lagoons represent liquid capture systems for open feedlots, they were considered herein as a manure nutrient reservoir and source. Comparisons of manure nutrients and manure nutrient output from lagoons or pits are independent of the complete manure management system represented by samples submitted. Data were further categorized by cattle type (Beef or Holstein) and targeted dietary energy value (Grower or Finisher). Beef-type cattle represent steers and heifers of varying beef breeds fed for beef production. Holstein-type cattle represent Holstein steers fed for beef production. Grower diets are fed early in the feedlot phase and rely on a greater forage inclusion rates and as such are lower in energy value than Finisher diets. Only samples for which all categorical descriptions existed were retained for a statistical analysis to determine effects of feedlot design, cattle type and targeted dietary energy value. Manure nutrients were expressed as kg nitrogen (N), phosphate (P_2O_5) or potash (K_2O)/tonne of as-is material (solid) or as kg of these nutrients/3,785 L (liquid). Because only finisher type diets were contained in the liquid dataset effect of energy value was dropped from the model.

A combined dataset (n = 483) was analyzed with projected annual cattle manure production values of 2.7 and 4.5 tonne/hd or 9,463 gal/hd, respectively, for Open lot,

Pack and Pit facility designs to project the effects of facility design on manure nutrient contributions per animal head space. Estimates of facility manure output were derived from commonly accessed publications (MWPS, 2004; ASAE, 2005). Estimates of manure production were used in lieu of measured values as these data were not available.

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Cary, NC). The model statement included terms for facility type, diet and cattle type, with effects of year and month of sample collection retained in the model as random effects. Effects of month and year were evaluated by conducting a secondary analysis in which effects of these variables were ignored. The Sawa's Bayesian Information Criteria (BIC) values were compared with the model with lowest BIC value considered the best fit of the data. Values for BIC between models containing month and year as a random effect against those ignoring the effect of month and year were similar. This finding indicates that within type of manure, sampling year or month has no effect on manure nutrient content. Mean separation was determined using least square differences. Solid and liquid manure types were evaluated separately. Statistical significance was characterized at $\alpha < 0.05$ and a tendency for significance at $0.05 < \alpha < 0.10$.

Results

The impact of facility design on N concentration was dependent on sample type (Table 3.1).

Table 3.1. Least square means ± standard errors of liquid or solid manure nutrient concentrations (as-is) for samples collected from pens within various feedlot designs

	Nitrogen	Phosphate, P_2O_5	Potash, K_2O
Liquid manure	----------kg/3,785 L----------		
Lagoon [a]	4.0 ± 2.6 [a]	2.3 ± 1.6 [a]	6.3 ± 4.2 [a]
Indoor pit [b]	22.6 ± 2.6 [b]	10.3 ± 1.6 [b]	16.6 ± 4.3 [b]
Cattle type			
Beef	11.8 ± 2.5 [a]	5.7 ± 1.6 [x]	10.3 ± 4.2
Holstein	14.9 ± 2.6 [b]	6.8 ± 1.6 [y]	12.6 ± 4.3
Solid manure	----------kg/t----------		
Open lot	8.3 ± 0.5	5.6 ± 0.6 [a]	7.4 ± 0.5
Manure pack	8.2 ± 0.5	4.7 ± 0.6 [b]	7.5 ± 0.6
Stockpile	8.6 ± 0.5	6.0 ± 0.6 [a]	8.1 ± 0.5
Cattle type			
Beef	9.0 ± 0.5 [a]	6.4 ± 0.5 [a]	8.2 ± 0.5 [a]
Holstein	7.7 ± 0.5 [b]	4.4 ± 0.6 [b]	7.2 ± 0.6 [b]
Diet type			
Finisher	8.2 ± 0.4	5.8 ± 0.5	7.2 ± 0.4 [x]
Grower	8.5 ± 0.7	5.1 ± 0.7	8.2 ± 0.7 [y]

[a, b] Means within category or source with uncommon superscripts differ ($P < 0.05$).
[x, y] Means within category with uncommon superscripts differ ($0.05 > P < 0.10$).

Within liquid samples, concentrations of N were greater in Pit than Lagoon ($P < 0.01$); however, N concentration of solid samples did not differ across feedlot facility design ($P = 0.57$). Phosphate concentration differed between facility types within both sample types ($P < 0.01$). Pit P_2O_5 was greater than Lagoon P_2O_5 concentration ($P < 0.01$). Pack P_2O_5 was less than both Open lot and Stockpile P_2O_5 ($P \leq 0.04$); however, P_2O_5 concentration did not differ between Open lot and Stockpile facilities ($P = 0.20$). Facility type impacted K_2O concentration within liquid samples ($P < 0.01$) but did not differ between solid samples ($P = 0.11$). Similar to N and P_2O_5, Pit K_2O concentration was greater than Lagoon.

The impact of cattle type on manure nutrient concentration within liquid samples differed amongst nutrients. Nitrogen concentration was greater for Holstein than Beef ($P < 0.01$) cattle, P_2O_5 concentration tended to be greater for Holstein cattle than Beef ($P = 0.06$) whereas K_2O concentration did not differ between Holstein and Beef cattle ($P = 0.20$). In contrast, N, P_2O_5 and K_2O concentrations were greater for Beef cattle than Holstein in solid samples ($P < 0.01$).

The impact of diet type was only evaluated in solid samples. Manure N concentration did not differ between Grower and Finisher diets ($P = 0.65$). Similarly, manure P_2O_5 concentration did not differ with diet type ($P = 0.21$). In contrast, there was a tendency for greater K_2O concentration in Grower diets, as compared to Finisher diets ($P = 0.09$).

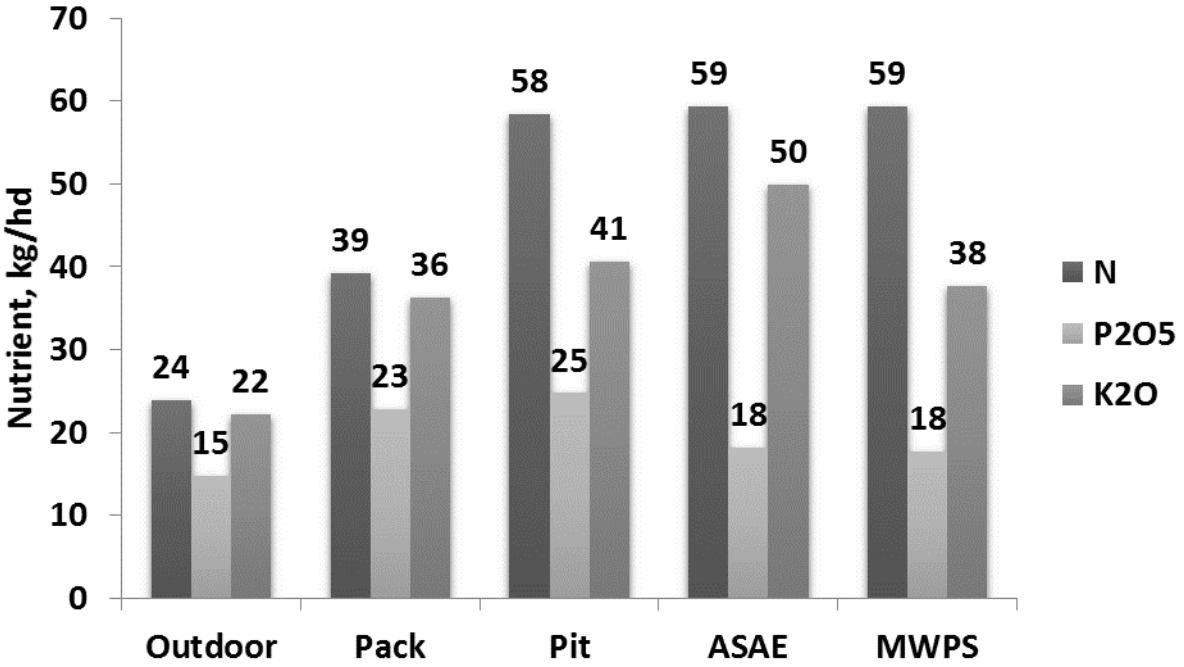

Figure 3.1. Estimated annual manure nutrient yield (kg/hd) derived from open lot (manure yield: 2.7 t/hd), manure pack (manure yield: 4.5 t/hd) or confinement pit (manure yield: 9,463 L/hd) cattle feedlots. Estimates of manure nutrient yield derived from commonly accessed publications (ASAE D384.2 MAR 2005; MWPS-18 Sec. 1, 2nd ed. 2004) are provided as a reference.

Yearly manure nutrient output (kg/hd) differed between facility type for all nutrients ($P < 0.05$; Figure 3.1). Nitrogen yield was greatest for Pit, intermediate for Pack and least for Open lot ($P < 0.01$). Phosphate yield was different ($P < 0.01$) between Open lot and confinement facility types (Pack and Pit) but did not differ ($P = 0.27$) amongst confinement facility types, with a lower P_2O_5 yield observed for Open lot compared to Pack and Pit. Similarly, K_2O yield was different ($P < 0.01$) between Open lot and confinement facility types and did not differ ($P = 0.11$) between confinement facility types, with a lower K_2O yield observed for Open lot compared to confinement facilities.

Discussion

Manure nutrient concentrations varied significantly between type of liquid storage, with increased nutrient capture in Pit facilities across all nutrients, compared to Lagoon; however, the magnitude of the difference between Pit and Lagoon N, P_2O_5 and K_2O concentrations differed. Pit N and P_2O_5 concentrations were 8.5 and 4.4 times greater, respectively, than Lagoon concentrations while K_2O concentration was only 2.6 times greater for Pit. Differences in manure nutrient capture between liquid systems are a function of differences in manure movement through each system. In slatted floor over a deep pit facilities, feces and urine are captured directly in the pit underneath the animals. In contrast, nutrient discharge entering a lagoon travels across the feedlot surface prior to capture and solids remain on the feedlot surface. Exposure of manure nutrients to the environment during travel to the lagoon increases the rate of N volatization to ammonia (NH_3) with factors such as wind speed and rain fall altering the rate of N volatization (Arogo et al., 2006). Additionally, significant N volatization was observed during the holding of manure in open lagoons (Westerman and Zhang, 1997). The primary route of P loss is runoff from the feedlot surface (Sharpley et al., 1994) and, in well-designed systems, total runoff is expected to be captured in lagoons. The reduction of P_2O_5 capture in Lagoon, relative to Pit designs, is likely a result of a large percentage of P remaining on the feedlot surface in the solid portion of manure as the main route of P excretion in cattle is feces (Betteridge et al., 1986; Morse et al., 1992). The magnitude of difference between Pit and Lagoon capture of K_2O was the smallest. Unlike P, K is primarily excreted in the urine (NRC, 2005); thus, only a small percentage of K would be expected to be retained in the solids on the feedlot surface and a greater proportion of excreted K

would be captured by lagoon designs. A reduction in K_2O concentration in Lagoon, as compared to Pit, is likely a function of dilution of manure nutrients from rainfall entering Lagoon systems. The dilution factor of rainfall would also contribute to the decrease in as-is nutrient concentration of Lagoon N and P_2O_5.

Nitrogen concentration did not differ between solid samples. Although there may be differences in rate of N volatization to NH_3 between bed packs and open lots, direct comparisons are not available in the literature. However, NH_3 volatization follows the same seasonal pattern in bedded pack facilities as has been previously described in open lots, with the highest concentrations observed during warm months, lowest during cold months and intermediate during months with moderate temperatures (Spiehs et al., 2011). Loss of N through runoff is expected to be essentially zero in well-designed Pack facilities. Although manure nutrient capture is expected to increase with Pack facilities due to decrease in run-off and potential decreases in NH_3 volatization through decreased exposure of manure to rainfall, concentration of N between solid sample types likely remain similar due to the addition of bedding materials resulting in a dilution of manure nutrients. Corn stover is a common bedding utilized in the Upper Midwest in bedded-packs and estimated to contain 6.5 % crude protein and 0.09 % P on a dry matter basis (NRC, 2000). Phosphate concentration in solid samples was lower for Pack, compared to Open lot and Stockpile, but did not differ between Open lot and Stockpile. As with N, a reduction in P_2O_5 concentration for Pack is likely explained through dilution of manure with bedding materials.

Greater concentrations of N, P_2O_5 and K_2O were observed in solid manure samples derived from pens housing Beef cattle. In contrast, N concentration was greater and P_2O_5 concentration tended to be greater for Holstein cattle in liquid samples. This may be a function of differences in days on feed and phase of feeding represented between beef and Holstein steer production systems. Holsteins enter the feedlot at lighter weights and remain on feed longer, thus having lower feed intakes and lower nutrient excretion on average throughout the feeding period in either open lot or bedded pack facilities. In contrast, slatted floor over deep pit facilities are primarily utilized during the final phase of feeding regardless of cattle type. Holsteins are typically finished to heavier weights and have a higher DMI (Rusta and Abneyb, 2005), which would contribute to greater nutrient excretion. Diet type did not influence N or P_2O_5 concentration; however, greater K_2O was observed for pens housing cattle on Grower diets. This is likely a reflection for a tendency for greater reliance on forages in Grower diets, which are generally higher in K than grains.

Manure nutrient concentrations determined in this analysis were utilized with estimates of manure production from their respective facility designs in order to estimate annual nutrient yield per headspace. Caution should be used in interpretation of this data, as projections are based on an average manure output for each facility type rather than the measured manure output for each individual facility and corresponding manure nutrient sample analysis. Estimates of facility manure output were derived from commonly accessed publications (MWPS, 2004; ASAE, 2005). Manure production estimates were utilized in light of the difficulties in measuring manure output for each facility.

Recognizing that a number of factors impact manure nutrient output, the ultimate value in the resulting projections of annual nutrient yield per headspace lie in the comparisons between facilities derived from this exercise rather than the absolute values reported. Increased N, P_2O_5 and K_2O capture for confinement facilities, as compared to Open lot facilities, is likely a result of containment of manure runoff. Yearly P_2O_5 and K_2O capture did not differ between confinement facility types, which is expected as in contrast to N, P and K are not released into the atmosphere. Increased N capture in for Pit facilities over Pack is likely attributed to a decrease in NH_3 volatilization which is supported by *in vitro* observations that N emissions are significantly less for liquid manure as compared to a simulated straw bed-pack (Dewes, 1999).

Maximum manure N recovery was calculated using ASAE D384.2, wherein values were derived from simple production of urine and manure to represent the maximum manure N recovery values. This maximum value was compared to nutrients in manure samples in this data set. Estimated manure N yield from Pit using manure samples contained in this dataset demonstrated a recovery of 98% of the total N excreted by a single animal unit space yearly. Applying the same logic, and ignoring the contributions of bedding material in Pack, these barns recover 66% of the total N excreted by a single animal unit space yearly. Zehnder et al. (2000) demonstrated that N recovery values approached 75% in manure bed pack buildings in the winter while only 50% of N produced by the animal was recovered in the summer. Seasonal changes in N recovery in bed packs is likely a reflection in temperature driven changes in NH_3 volatization (Ayadi et al., 2015b). Corresponding N recovery value for Open lot using

this approximation is 40%. An increase in P_2O_5 yield, relative to ASAE and MWPS estimates was observed for confinement facilities and is likely explained by increased availability and use of corn ethanol co-products in the current survey. Relative to dry rolled corn, wet distillers grains plus solubles contributes 4.4 times greater P to the diet on a dry matter basis (NRC, 2000).

Best management practices for manure application consist of determining nutrient concentration of manure through testing and matching nutrient provision with the existing level of soil nutrients and projected crop demand. Increasing focus on the environmental impact of livestock production necessitates a proactive approach to managing manure nutrients. The results generated by this study deliver valuable information to feedlot operations considering expansion that allows for more precise projections of crop land required to offset manure production of a given facility type and production system.

Literature Cited

Aalhus, J. L., A. L. Schaefer, A. C. Murray, and S. D. M. Jones. 1992. The effect of ractopamine on myofibre distribution and morphology and their relation to meat quality in swine. Meat Sci. 31:397-409.

Anderson, B. B. 1980. Feeding trials describing net requirements for maintenance as dependent on weight, feeding level, sex and genotype. Ann. Zootech. 29:85-92.

Anderson, D. M., P. M. Glibert, and J. M. Burkholder. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. Estuaries. 25:704-726.

Anderson, P. 2017. Predicting gain from intake. Pp. 65-77 in The 2017 Plains Nutrition Council Spring Conference Proceedings, April 13-14 2017, San Antonio, Tx. Texas A&M Agrilife Research and Extension Center, Amarillo, Tx.

Anthony, J. C., T. G. Anthony, S. R. Kimball, and L. S. Jefferson. 2001. Signaling pathways involved in translational control of protein synthesis in skeletal muscle by leucine. J. Nutr. 131:856S-860S.

ARC (Agricultural Research Council). 1980. The Nutrient Requirements of Ruminant Livestock: Technical Review. Farnham Royal, UK; Commonwealth Agricultural Bureaux.

Archibeque, S., D. Miller, H. Freetly, E. Berry, and C. Ferrell. 2007a. The influence of oscillating dietary protein concentrations on finishing cattle. I. feedlot performance and odorous compound production. J. Anim. Sci. 85:1487-1495.

Archibeque, S., H. Freetly, N. Cole, and C. Ferrell. 2007b. The influence of oscillating dietary protein concentrations on finishing cattle. II. Nutrient retention and ammonia emissions. J. Anim. Sci. 85:1496-1503.

Armstrong, T. A., D. J. Ivers, J. R. Wagner, D. B. Anderson, W. C. Weldon, and E. P. Berg. 2004. The effect of dietary ractopamine concentration and duration of feeding on growth performance, carcass characteristics, and meat quality of finishing pigs. J. Anim. Sci. 82:3245-3253.

Arogo, J., P. W. Westerman, A. J. Heber, W. P. Robarge, and J. J. Classen. 2006. Pp 41-88 in Ammonia emissions from animal feeding operations. Animal Agriculture and the Environment: National Center for Manure and Animal Waste Management White Papers.

American Society of Agricultural Engineers (ASAE). 2005 Manure production and characteristics. ASAE D384.2 MAR2005.

Awadeh, M. S., E. C. Titgemeyer, G. F. Schroeder, and D. P. Gnad. 2006. Excess amino acid supply improves methionine and leucine utilization by growing steers. J. Anim. Sci. 84:1801-1810.

Ayadi, F. Y., E. L. Cortus, D. E. Clay, and S. A. Hansen. 2015a. Isotope ratio mass spectrometry monitoring of nitrogen volatilization from beef cattle feces and 15N-labeled synthetic urine. Atmosphere. 6:641-649.

Ayadi, F. Y., E. L. Cortus, M. J. Spiehs, D. N. Miller, and G. D. Djira. 2015b. Ammonia and greenhouse gas concentrations at surfaces of simulated beef cattle bedded manure packs. Transactions of the ASABE. 58:783-795.

Bach, A., S. Calsamiglia, and M. D. Stern. 2004. Nitrogen metabolism in the rumen. J. Dairy. Sci. 88:(Esuppl)9-21.

Bardsley, R. G., S. M. J. Allock, N. W. Dumelow, J. A. Higgins, Y. V. Lasslett, A. K. Lockley, T. Parr, and P. J. Buttery. 1992. Effect of β-agonists on expression of calpain and calpastatin activity in skeletal muscle. Biochem. 74:267-273.

Baumgard, L. H., and R. P. Rhoads. 2012. Ruminant Nutrition Symposium: Ruminant production and metabolic responses to heat stress. J. Anim. Sci. 90:1855-1865.

Baumgard, L. H., J. B. Wheelock, S.R. Sanders, C. E. Moore, H. B. Green, M. R. Wadron, and R. P. Rhoads. 2011. Postabsorptive carbohydrate adaptations to heat stress and monensin supplementation in lacatating Holstein cows. J. Dairy Sci. 94:5620-5633.

Beermann, D. H., W. R. Buter, D. E. Hogue, V. K. Fishell, R. H. Dalrymple, C. A. Ricks, and C. G. Scanes. 1987. Cimaterol-induced muscle hypertrophy and altered endocrine status in lambs. J. Anim. Sci. 65:1514-1524.

Benson, D. W., T. Foley-Nelson, W. T. Chance, F. Zhang, J. H. James, and J. E. Fischer. 1991. Decreased myofibrillar protein breakdown following treatment with clenbuterol. J. of Sur. Res. 50:1-5.

Bergen, W. G., S. E. Johnson, D. M. Skjaerlund, A. S. Babiker, N. K. Ames, R. A. Merkel, and D. . Anderson. 1989. Muscle Protein Metabolism in Finishing Pigs Fed Ractopamine. J. Anim. Sci. 67:2255-2262.

Betteridge, K., W. Andrewes, and J. Sedcole. 1986. Intake and excretion of nitrogen, potassium and phosporus by grazing steers. The Journal of Agricultural Science. 106:393-404.

Bierman, S., G. Erickson, T. Klopfenstein, R. A. Stock, and D. Shain. 1999. Evaluation of nitrogen and organic matter balance in the feedlot as affected by level and source of dietary fiber. J. Anim. Sci. 77:1645-1653.

Bittner, C. J., M. A. Greenquist, D. B. Burken, A. L. Shreck, J. C. MacDonald, T. J. Klopfenstein, W. J. Platter, M. T. Van Koevering, N. A. Pyatt, and G. E. Erickson. 2017. Evaluation of ractopamine hydrochloride (Optaflexx) on growth performance and carcass characteristics of finishing steers across different feeding durations. J. Anim. Sci. 95:485-498.

Blum, J. W., W. Schnyder, P. L. Kunz, A. K. Blom, H. Bickel, and A. Schurch. 1985. Reduced and compensatory growth: Endocrine and metabolic changes during food restriction and refeeding in steers. J. Nutr. 115:417-424.

Breier, B. H., and P. D. Gluckman. 1991. The regulation of postnatal growth: Nutritional influences on endocrine pathways and function of the somatotrophic axis. Livest. Prod. 27:77-94.

Breier, G. H., J. J. Bass, J. H. Butler, and P. D. Gluckman. The somatotrophic axis in young steers: Influence of nutritional status on pulsatile release of growth hormone and circulating concentrations of insulin-like growth factor 1. J. Endocrinol. 111:209-215.

Bodine, S. C., T. N. Stitt, M. Gonzalez, W. O. Kline, G. L. Stover, R. Bauerlein, E. Alotchenko, A. Scrimgeour, J. C. Lawrence, D. J. Glass, and G. D. Yancopoulos. 2001. Akt/mtor pathway is a crucial regulator of skeletal muscle hypertrophy and can prevent muscle atrophy in vivo. Nat. Cell Biol. 3:1014-1019.

Brody, S. 1964. Bioenergetics and Growth. Reinhold, New York.

Bryant, T. C., T. E. Engle, M. L. Galyean, J. J. Wagner, J.D. Tatum, R. V. Anthony, and S. B. Laudert. 2010. Effects of ractopamine and trenbolone acetate implants with or without estradiol on growth performance, carcass characteristics, adipogenic enzyme activity, and blood metabolites in feedlot steers and heifers. J. Anim. Sci. 88:4102-4119.

Burroughs, W., D.K. Nelson, and D. R. Mertens. 1975. Protein physiology and its application in the lactating cow: The metabolizable protein feeding standard. J. Anim. Sci. 41: 933-944.

Butler, S. T., A. L. Marr, S. H. Pelton, R. P. Radcliff, M. C. Lucy, and W. R. Butler. Insulin restore GH responsiveness during lacation-induced negative energy blance in dairy cattle: effects on expression of IG-I and GH receptor 1A. J. Endocrinol. 176:205-207.

Buttery, P. J., B. G. Verson, and J. T. Pearson. 1978. Anabolic agents – some thoughts on their mode of action. Proc. Nutr. Soc. 37:311-315.

Byers, F. M. 1982. Patterns of energetic efficiency of tissue growth in beef cattle of four breeds. Pp. 92-95 in Energy Metabolism of Farm Animals: Proceedings of the 9th Symposium, September 1982, Lillehammer, Norway, F. Sundstol and A. Ekern, eds. EAAP Publication No. 29. Aas, Norway: Department of Animal Nutrition, Agricultural University of Norway.

Calkins, C. R., T. R. Dutson, C. G. Smith, Z. L. Carpenter, and G. W. Davis. 1981. Relationship of fiber type composition to marbling and tenderness of bovine muscle. J. Food Sci. 46:708-710.

Cant, J. P., B. W. McBride, and W. J. Croom Jr. 1996. The regulation of intestinal metabolism and its impact on whole animal energetics. J. Anim. Sci. 74:2541-2553.

Carstens, G. E., D. E. Johnson, K. A. Jonhson, S. K. Hotovy, and T., J. Symanski. 1989. Genetic variation in energy variation in energy expenditures of monozygous twin beef cattle at 9 and 20 months of age. Pp. 312-315 in Energy Metabolism of Farm Animals: Proceedings of the 11th Symposium, Septempber 18-24, 1988, Lunteren, Netherlands, Y. van der honing, ed. EAAP Publication No. 43. Wageningen, The Netherlands: Pudoc.

Carstens, G. E., D. E. Johnson, M. A. Ellenberger, and J. D. Tatum. 1991. Pp. 131 in Energy metabolism and composition of gain in beef steers exhibiting normal and compensatory growth. In: Energy Metabolism of Farm Animals. Eur. Assoc. Anim. Prod. Publ. No. 43.

Cevaca, M. J. and D. L. Hancock. 1994. Effects of anabolic steroids on nitrogen metabolism and growth of steers fed corn silage and corn-based diets supplemented with urea or combinations of soybean and feathermeal. J. Anim. Sci. 72:515-522.

Chizzotti, M. L., S. C. Valdares Filho, L. O. Tedeschi, F. H. M. Chizzotti, and G. E. Carstens. 2007. Energy and protein requirements for growth and maintenance of F1 Nellore x Red Angus bulls, steers, and heifers. J. Anim. Sci. 86:1588-1597.

Chizzotti, M. L., L. O. Tedeschi, and S. C. Valadares Filho. 2008. A meta-analysis of energy and protein requirements for maintenance and growth of Nellore cattle. J. Anim. Sci. 86:1588-1597.

Connor, E. E., S. Kahl, T. H. Elsasser, J. S. Parker, R. W. Li, C. P. Van Tassell, R. L. Baldwin, and S. M. Barao. 2010. Enhanced mitochondrial complex gene function and reduced liver size may mediate improved feed efficiency of beef cattle during compensatory growth. Funct. Integr. Genomics. 10:39-51.

Cole, N. A. 1999. Nitrogen retention by lambs fed oscillating dietary protein concentrations. J. Anim. Sci. 77:215-222.

Cole, N., R. Clark, R. Todd, C. Richardson, A. Gueye, L. Greene, and K. McBride. 2005. Influence of dietary crude protein concentration and source on potential ammonia emissions from beef cattle manure. J. Anim. Sci. 83:722-731.

Cole, N., L. Greene, F. McCollum, T. Montgomery, and K. McBride. 2003. Influence of oscillating dietary crude protein concentration on performance, acid-base balance, and nitrogen excretion of steers. J. Anim. Sci. 81:2660-2668.

Cordell, D., J. Drangert, and S. White. 2009. The story of phosphorus: Global food security and food for thought. Global Environ. Change. 19:292-305.

CSIRO (Commonwealth Scientific and Industrial Research Organization). 1990. Feeding Standards for Australian Livestock: Ruminants. Melbourne, Australia: CSIRO Publishing.

CSIRO. 2007. Nutrient Requirements of Domestical Ruminants. Collingwood, Australia: CSIRO Publishing.

da Silva, R. G. 1973. Improving tropical beef cattle by simultaneous selection for weight and heat tolerance. Heritabilities and correlations of the traits. J. Anim. Sci. 37:637-642.

Daverede, I., A. Kravchenko, R. Hoeft, E. Nafziger, D. Bullock, J. Warren, and L. Gonzini. 2004. Phosphorus runoff from incorporated and surface-applied liquid swine manure and phosphorus fertilizer. J. Environ. Qual. 33:1535-1544.

Davis, J. G., M. Young, and B. Ahnstedt. 1997. Soil characteristics of cropland fertilized with feedlot manure in the south platte river basin of colorado. J. Soil Water Conserv. 52:327-331.

Déry, P., and B. Anderson. 2007. Peak phosphorus. Energy Bulletin. 13

Dewes, T. 1999. Ammonia emissions during the initial phase of microbial degradation of solid and liquid cattle manure. Bioresour. Technol. 70:245-248.

Divito, G. A., H. E. Echeverría, F. H. Andrade, and V. O. Sadras. 2015. Diagnosis of S deficiency in soybean crops: Performance of S and N: S determinations in leaf, shoot and seed. Field Crops Res. 180:167-175.

Done- Currie, J. R., M. Wodzicka-Tomaszweksa, and J. J. Lynch. 1984. The effects of thermoregulatory behavior on the heat loss from shorn sheep as measure by a model ewe for micro-climate integration. App. Anim. Behav. Sci. 13:59-70.

Doranalli, K., G. B. Penner, and T. Mutsvangwa. 2011. Feeding oscillating dietary crude protein concentrations increases nitrogen utilization in growing lambs and this response is partly attributable to increased urea transfer to the rumen. J. Nutr. 141:560-567.

Drouillard, J. S., C. L. Ferrell, T. J. Kopfenstein, and R. A. Britton. 1991. Compensatory growth following metabolizable protein or energy restrictions in beef steers. J. Anim. Nutr. 69:811-818.

Dunn, J. D., B. J. Johnson, J. P. Kayer, A. T. Waylan, E. K. Sissom, and J. S. Drouillard. 2003. Effects of flax supplementation and a combined trenbolone acetate and estradiol implant on circulating insulin-like growth factor-1 and muscle insulin-like growth factor-1 messenger RNA levels in beef cattle. J. Anim. Sci. 81:3028-3034.

Eghball, B. 2003. Leaching of phosphorus fractions following manure or compost application. Commun. Soil Sci. Plant Anal. 34:2803-2815.

Eghball, B., J. F. Power, J. E. Gilley, and J. W. Doran. 1997. Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. J. Environ. Qual. 26:189-193.

Elam, N. A., J. T. Vasconcelos, G. Hilton, D. L. VanOverbeke, T. E. Lawrence, T. H. Montgomery, W. T. Nicols, M. N. Streeter, J. P. Hutchenson, D. A. Yates, and M. L. Galyean. 2008. Effect of zilpaterol hydrochloride duration of feeding performance and carcass characteristics of feedlot cattle. J. Anim. Sci. 87:2133-2141.

Erickson, G. E., and T. J. Klopfenstein. 2001. Managing N inputs and the effect on N losses following excretion in open-dirt feedlots in Nebraska. Scientific World J. 1:830-835.

FAO. 2015. Current world fertilizer trends and outlook to 2015. Rome.

Farran, T., G. E. Erickson, T. Klopfenstein, C. Macken, and R. Lindquist. 2006. Wet corn gluten feed and alfalfa hay levels in dry-rolled corn finishing diets: Effects on finishing performance and feedlot nitrogen mass balance. J. Anim. Sci. 84:1205-1214.

Ferguson, R. B., J. A. Nienaber, R. A. Eigenberg, and B. L. Woodbury. 2005. Long-term effects of sustained beef feedlot manure application on soil nutrients, corn silage yield, and nutrient uptake. J. Environ. Qual. 34:1672-1681.

Ferrell, C. L., and T. G. Jenkins. 1984. Energy utilization by mature nonpregnant, nonlactating cows of different breeds. J. Anim. Sci. 58:234-243.

Ferrell, C. L., and T. G. Jenkins. 1987. Influence of biological type on energy requiremetns. Pp. 1-7 in Proceedings of the Grazing Livestock Nutrition Conference. Stillwater: Oklahoma Agricultural Experiment Station, Oklahoma State University.

Ferraretto, L. F., C. S. Ballard, C. J. Sniffen, and I. Shinzato. 2016. Influences of essential amino acid balancing postpartum on lactation performance by dairy cows through meta-analysis. J. Anim. Sci. 94:(ESuppl5)730-731.

Florini, J. R., D. Z. Ewton, and S. A. Coolican. 1996. Growth hormone and the insulin-like growth factor system in myogenesis. Endcrinol. Rev. 17:481-517.

Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578.

Galyean, M. L., and L. O. Tedeschi. 2014. Predicting microbial protein synthesis in beef cattle: Relationships to total digestible nutrients intake and crude protein. J. Anim. Sci. 92:5099-5111.

Garrett, W. N. 1970. The influence of sex on the energy requirements of cattle for maintenance and growth. Pp. 101-104 in Energy Metabolism of Farm Animals: Proceedings of 5th Symposium, September 1970, Vitznau, Switzerland. EAAP Publication No. 13. Zurich: Juris Verlag.

Garrett, W. N. 1971. Energetic efficiency of beef and dairy steers. J. Anim. Sci. 32:451-456.

Garrett, W. N. 1980. Energy utilization by growing cattle as determined in 72 compariative slaughter experiments. Pp. 3-8 in Energy Metabolism: Proceedings

of the 8th Symposium, September 1979, Cambridge, England. L E. Mount, ed. EAAP Publication No. 26. London: Butterworths.

Garlick, P. J. 2005. The role of leaucine in the regulation of protein metabolism. J. Nutr. 135:1153S-1156S.

Garlick, P. J., and I. Grant. 1988. Amino acid infusion increases the sensitivity of muscle protein synthesis in vivo to insulin. Biochem. J. 254:579-584.

Gerrits, W. J., G. H. Tolman, J. W. Schrama, S. Tamminga, M. W. Bosch, and M. W. Verstegen. 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci. 74:2129-2139.

Gilbertson, C. B., T. McCalla, J. Ellis, O. Cross, and W. Woods. 1971. Runoff, solid wastes, and nitrate movement on beef feedlots. J. Water Pollut. Control Fed. 1:483-493.

Gleghorn, J., N. Elam, M. Galyean, G. Duff, N. Cole, and J. Rivera. 2004. Effects of crude protein concentration and degradability on performance, carcass characteristics, and serum urea nitrogen concentrations in finishing beef steers. J. Anim. Sci. 82:2705-2717.

Gressley, T., and L. Armentano. 2005. Effect of abomasal pectin infusion on digestion and nitrogen balance in lactating dairy cows. J. Dairy Sci. 88:4028-4044.

Hall, M., and G. Huntington. 2008. Nutrient synchrony: Sound in theory, elusive in practice. J. Anim. Sci. 86(Esuppl_14):287-292.

Gill, D. R., M. C. King, H. G. Dolezal, J. J. Martin, and C. A. Strasia. 1993a. Starting age and background: Effects on feedlot performance of steers. Oklahoma Agric. Exp. Sta. Rep. MP-933:197.

Gill, D. R., F. R. Owens, M. C. King, and H. G. Dolezal. 1993b. Body composition of grazing or feedlot steers differing in age and background. Oklahoma Agric. Rep. MP-933:185.

Glass, D. J. 2003. Signaling pathways that mediate skeletal muscle hypertrophy and atrophy. Nat. Cell Biol. 5:87-90.

Hanna, R. A., R. L. Campbell, and P. L. Davies. 2008. Calcium-bound structure of calpain and its mechanism of inhibition by calpastatin. Nature. 456:409-412.

Hahn-Windgassen, A., V. Nogueira, C. Chen, J. E. Skeen, N. Sonenberg, and N. Hay. 2005. Akt activates the mammalian target of rapamycin by regulating cellular ATP level and AMPK activity. J. of Biol. Chem. 380:32081-32089.

Han, B., J. Tong, M. J. Zhu, C. Ma, and M. Du. 2008. Insulin-like growth factor-1(IGF-1) and leucine activate pig myogenic satellite cells through mammalian target of rapamycin (mTOR) pathway. Mol. Repro. Devel. 75:810-817.

Hannon, K., A. Gronowski, and A. Trenkle. 1991. Relationship of liver and skeletal muscle IGF-1 mRNA to plasma GH profile, production of IGF-1 by liver, plasma IGF-1 concentrations, and growth rates of cattle. Pp. 155-162 in Proceedings of the Society for Experimental Biology and Medecine.

Hao, X., C. Chang, and F. J. Larney. 2004. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. J. Environ. Qual. 33:37-44.

Hausdorff, W. P., M. J. Lohse, M. Bouvier, S. B. Liggett, M. G. Caron, and R. J. Lefkowitz. 1990. Two kinases mediate agonist-dependent phosphorylation and desensitization of the beta 2-adrenergic receptor. Symp. Soc. Exp. Biol. 44:225-240.

Hayden, J. M., J. E. Williams, and J. J. Collier. 1993. Plasma growth hormone, insulin-like growth factor, insulin, and thyroid hormone association with body protein and fat accretion in steers undergoing compensatory gain after dietary energy restriction. J. Anim. Sci. 71:3327-3338.

Heaney, D. P., and W. J. Pigden. 1963. Interrelationships and Conversion Factors between Expressions of the Digestible Energy Value of Forages. J. Anim. Sci. 22: 956-960.

Henning, P., D. Steyn, and H. Meissner. 1991. The effect of energy and nitrogen supply pattern on rumen bacterial growth in vitro. Anim. Prod. 53:165-175.

Hornick, J. L., C. Van Eenaeme, O. Gerard, I Dufrasne, and L. Istasse. 2000. Mechanisms of reduced and compensatory growth. Domest. Anim. Endocrinol. 19:121-132.

Horowitz, M. 2002. From molecular and cellular to integrative heat defense during exposure to chronic heat. Compar. Biochem. Physiol. Part A. 131:475-483.

Hosford, A. D., J. E. Hergenreder, J. K. Kim, J. O. Baggerman, F. R. B. Ribeiro, M. J. Anderson, K. S. Spivey, W. Rounds, and B. J. Johnson. 2015. Effects of supplemental lysine and methionine with zilpaterol hydrochloride on feedlot

performance, carcass merit, and skeletal muscle fiber characteristics in finishing feedlot cattle. J. Anim. Sci. 93:4532-4544.

Hulbert, A. J., and P. L. Else. 2004. Basal metabolic rate: history, composition, regulation, and usefulness. Physiol. Biochem. Zoo. 77:869-876.

Hunter, R. A., and J. E. Vercoe. 1987. Reduction of energy requirements of steers fed on low-quality roughage diets using trenbolone acetate. Br. J. Nutr. 58:477-489.

Huntington, G., and S. Archibeque. 2000. Practical aspects of urea and ammonia metabolism in ruminants. J. Anim. Sci. 77(E-Suppl):1-11.

James, T., D. Meyer, E. Esparza, E. DePeters, and H. Perez-Monti. 1999. Effects of dietary nitrogen manipulation on ammonia volatilization from manure from Holstein heifers. J. Dairy Sci. 82:2430-2439.

Jenkinds, T. G., and C. L. Ferrell. 1984. Characterization of postweaning traits of Simmental and Hereford bulls and heifers. Anim. Prod. 39:355-364.

Jiang, H., and X. Ge. 2014. Mechanism of growth hormone stimulation of skeletal muscle growth in cattle. J Anim. Sci. 92:21-29.

Johnson, B. J., S. B. Smith, and K. Y. Chung. 2014. Historical overview of the effect of β-adrenergic agonists on beef cattle production. Asian Australas. J. Anim. Sci. 27:757-766.

Johnson, B. J., N. Halstead, M. E. White, M. R. Hathaway, A. DiConstanzo, and W. R. Dayton. 1998. Activation state of muscle satellite cells isolated from steers implanted with a combined trenbolone acetate and estradiol implant. J. Anim. Sci. 76:2779-2786.

Johnson, J., A. Shreck, B. Nuttelman, D. Burken, G. Erickson, M. Rincker, M. Cecava, and T. Klopfenstein. 2015. Effects of twenty percent alkaline-treated corn stover without or with yucca extract on performance and nutrient mass balance of finishing steers fed modified distillers grains–based diets. J. Anim. Sci. 93:3034-3043.

Karen, E. N., and B. E. Olson. 2006. Thermal balance of cattle grazing winter range: Model application. J. Anim. Sci. 84:1238-1247.

Kennedy, P., and L. Milligan. 1980. The degradation and utilization of endogenous urea in the gastrointestinal tract of ruminants: A review. Can. J. Anim. Sci.. 60:205-221.

Kim, K., D. E. Kaiser, and J. Lamb. 2013. Corn response to starter fertilizer and broadcast sulfur evaluated using strip trials. Agron. J. 105:401-411.

Kimball, S. R. and L. S. Jefferson. 2004. Molecular mechanism through which amino acids mediate signaling through the mammalian target of rapamycin. Curr. Opin. Clin. Nutr. Metab. Care. 7:39-44.

Kissinger, W. F., G. E. Erickson, and T. J. Klopfenstein. 2006. Summary of manure amounts, characteristics, and nitrogen mass balance for open feedlot pens in summer compared to winter. J. Anim. Sci. 84(E-Suppl):132-133.

Klieber, M. 1947. Body size and metabolic rate. Physiol. Rev. 27:511-541.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223-1231.

Koenig, K., and K. Beauchemin. 2013. Nitrogen metabolism and route of excretion in beef feedlot cattle fed barley-based backgrounding diets varying in protein concentration and rumen degradability. J. Anim. Sci. 91:2295-2309.

Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgadir, and S. St-Gean. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim. Sci. 74:2473-2481.

Lee, C. Y. D. M. Henricks. G. C. Skelley, and L. W. Grimes. 1990. Growth and hormonal response of intact and castrate male cattle to trenbolone acetate and estradio. J. Anim. Sci. 68:2682-2689.

Larney, F. J., K. E. Buckley, X. Hao, and W. P. McCaughey. 2006. Fresh, stockpiled, and composted beef cattle feedlot manure. J. Environ. Qual. 35:1844-1854.

Lapierre, H., D. Pacheco, R. Berthiaume, D. R. Ouellet, C. G. Schwab, P. Dubreuil, G. Holtrop, and G. E. Lobley. 2006. What is the true supply of amino acids for a dairy cow? J. Dairy Sci. 89(E-Suppl):1-14.

Lobley, G. E., A. Connell, g. S. Mollison, A. Brewer, B. I. Harris, V. Buchan, and H. Galbraith. 1985. The effects of a combined implant of trenbolone acetate and oestradio-17β on protein and energy metabolism in growing beef steers. Br. J. Nutr. 54:681-694.

Lofgreen, G. P., D. L. Bath, and H. T. Strong. 1963. Net energy of successive eincrements of feed above maintenance for beef cattle. J. Anim. Sci. 19:392-403.

Lofgreen, G. P., and W. N. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J. Anim. Sci. 27:793-806.

Luebbe, M., G. Erickson, T. Klopfenstein, M. Greenquist, and J. Benton. 2011a. Composting or stockpiling of feedlot manure in Nebraska: Nutrient concentration and mass balance. Prof. Anim. Sci. 27:83-91.

Luebbe, M., G. Erickson, T. Klopfenstein, M. Greenquist, and J. Benton. 2011b. Effect of dietary cation-anion difference on urinary pH, feedlot performance, nitrogen mass balance, and manure pH in open feedlot pens. J. Anim. Sci. 89:489-500.

Luebbe, M., J. Patterson, K. Jenkins, E. Buttrey, T. Davis, B. Clark, F. McCollum, N. Cole, and J. MacDonald. 2012. Wet distillers grains plus solubles concentration in steam-flaked-corn-based diets: Effects on feedlot cattle performance, carcass characteristics, nutrient digestibility, and ruminal fermentation characteristics. J. Anim. Sci. 90:1589-1602.

Lowman, B. G., E. R. Neilson, and E. A. Hunter. 1985. The effect of growth promotors on fattening cattle: Growth, intake and carcass composition. Anim. Prod. 40:538.

Mackinnon, M. J., K. Meyer, D. J. S. Hetzel. 1991. Genetic variation and covarion for growth, parasite resistance and heat tolerance in tropical cattle. Livestock Prod. Sci. 27:105-122.

Mathis, C. P., R. C. Cochran, J. S. Heldt, B. C. Woods, I. E. Abdelgadir, K. C. Olson, E. C. Eitgemeyer, and E. S. Vanzant. 2000. Effects of supplemental degradable intake protein on utilization of medium- to low-quality forages. J. Anim. Sci. 78:224-232.

MacRae, J. C., and G. E. Lobley. 1991. Physiological and metabolic implications of conventional and novel methods for the manipulation of growth and production. Livest. Prod. Sci. 27:43-59.

Mallarino, A. P., M. U. Haq, and N. Dagna. 2014. Crop availability of phosphorus in beef manure. Leopold Center Completed Grant Reports. 466.

May, M., J. DeClerck, M. Quinn, N. Dilorenzo, J. Leibovich, D. Smith, K. Hales, and M. Galyean. 2010. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: Feedlot cattle performance, carcass characteristics, and apparent total tract digestibility. J. Anim. Sci. 88(:2433-2443.

McNeel, R. L., and H. J. Mersmann. 1999. Distribution and quantification of beta1-, beta2-, and beta3-adrenergic receptor subtype transcripts in porcine tissues. J. Anim. Sci. 77:611-621.

Mersmann, H. J. 1998. Overview of the effects of β-adrenergic receptor agonists on animal growth including mechanisms of action. J. Anim. Sci. 76: 160-172.

Mills, S. E. 2002. Biological basis of the ractopamine response. J. Anim. Sci. 80(E-Suppl):28-32.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranson, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, D. T. Bechtol, E. Johnson, T. TerHume, and T. H. Montgomery. 2009. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 87:1374-1383.

Murphy, T. A., and S. C. Loerch. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics, and composition. J. Anim. Sci. 72:2497-2507.

Morse, D., H. Head, C. Wilcox, H. Van Horn, C. Hissem, and B. Harris. 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. Dairy Sci. 75:3039-3049.

MidWest Plan Service (MWPS). 2004. Manure characteristics. MWPS-18-S1.

Ni, J., A. J. Heber, D. T. Kelly, and A. L. Sutton. 1998. Mechanism of gas release from liquid swine wastes. Pp. 1 in ASAE Annual Meeting.

NRC (National Research Council). 1981. Effect of Environment on Nutrient Requirements of Domestic Animals. Washington, DC: National Academy Press.

NRC. 1984. Nutrient Requirements of Beef Cattle, 6th Rev. Ed. Washington, DC: National Academy Press.

NRC, 1985. Ruminant Nitrogen Usage. Washington, DC: National Academy Press.

NRC. 1989. Nutrient Requirements of Dairy Cattle, 6th Rev. Ed. Washington, DC: National Academy Press.

NRC. 1996. Nutrient Requirements of Beef Cattle, 7th Rev. Ed. Washington, DC: National Academy Press.

NRC. 2000. Nutrient Requirements of Beef Cattle, Updated 7th Rev. Ed. Washington, DC. National Academy Press.

NRC. 2001. Nutrient Requirements of Dairy Cattle, 7th Rev. Ed. Washington, DC: National Academy Press.

NRC. 2005. Minerla tolerance of animals. . Washington, DC: National Academy Press.

NRC. 2012. Nutrient Requirements of Swine, 11th Rev. Ed. Washington, DC: National Academy Press.

NRC. 2016. Nutrient Requirements of Beef Cattle, 8th Rev. Ed. Washington, DC: National Academy Press.

O'Connor, J. D., C. J. Sniffen, D. G. Fox, and W. Chalupa. 1993. A net carbohydrate and protein system for evaluating cattle diets: IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298-1311.

O'Leary, M., and G. Rehm. 1990. Nitrogen and sulfur effects on the yield and quality of corn grown for grain and silage. J. Prod. Agric. 3:135-140.

Old, C. A., and W. N. Garrett. 1987. Effects of energy intake on energetic efficiency and body composition of beef steers differing in size at maturity. J. Anim. Sci. 65:1371-1380.

Oldham, J. D. 1987. Efficiences of amino acid utilization. Pp. 171-186 in Feed Evaluation and Protein Requirement Systems for Ruminants, R. Jarrige, and G. Alderman, eds. Luxembourg: Commission of European Communities.

Oscar, T. P. 1995. Lipid mobilization from chicken fat cells. In: Biology of Fat in Meat Animals: Current Advances (Eds. S. B. Smith and D. R. Smith). American Society of Animal Science. Champaign, IL, USA. Pp. 93-112.

Ouellet, D. R., M. Demers, G. Zuur, G. E. Lobley, J. R. Seoane, J. V. Nolan, and H. Lapierre. 2002. Effect of dietary fiber on endogenous nitrogen flows in lactating cows. J. Dairy Sci. 85:3013-3025.

Owens, F. N., D. R. Gill, D. S. Secrist, and S. W. Coleman. 1995. Review of some aspects of growth and development of feedlot cattle. J. Anim. Sci. 73:3152-3172.

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138-3150.

Owens, F. N, S. Qi, and D. A. Sapienza. 2014. Invited review: Applied protein nutrition of ruminants-Current status and future directions. Prof. Anim. Sci. 30: 150-179.

Pampusch, M. S., B. J. Johnson, M. E. White, M. R. Hathaway, J. D. Dunn, A. T. Waylan, and W. R. Dayton. 2003. Time course of changes in growth factor mRNA levels in muscle of steroid-implanted and nonimplanted steers. J. Anim. Sci. 81:2733-2740.

Pampusch, M. S., M. E. White, M. R. Hathaway, T. J. Baxa, K. Y. Chung, S. L. Parr, B. J. Johnson, W. J. Weber, and W. R. Dayton. Effects of imlants of trenbolone acetate, estradiol, or both, on muscle insulin-like growth factor-I, insulin-like growth factor-I reception, estrogen receptor-α, and androgen receptor messenger ribonucleic acid levels in feedlot steers. J. Anim. Sci. 86:3418-3423.

Parker, D. B., S. Pandrangi, L. Greene, L. Almas, N. Cole, M. Rhoades, and J. Koziel. 2005. Rate and frequency of urease inhibitor application for minimizing ammonia emissions from beef cattle feedyards. Trans. ASAE. 48:787-793.

Parkinson, R., P. Gibbs, S. Burchett, and T. Misselbrook. 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresour. Technol. 91:171-178.

Parr, T., R. G. Bardsley, R. S. Gilmour, and P. J. Buttery. 1992. Changes in calpain and calpastatin mRNA induced by β-adrenergic stimulation of bovine skeletal muscle. Euro. J. Biochem. 208:333-339.

Perry, T. C., and D. G. Fox. 1997. Predicting carcass composition and individual feed requirement in live cattle widely varying in body size. J. Anim. Sci. 75:300-307.

Pritchard, R. 2017. Estimating energy values of feedstuffs – approaches and problems. Pp. 47-52 in The 2017 Plains Nutrition Council Spring Conference Proceedings, April 13-14 2017, San Antonio, Tx. Texas A&M Agrilife Research and Extension Center, Amarillo, Tx.

Prossnitz, E. R., J. B. Arterburn, H. O. Smith, T. I. Oprea, L. A. Sklar, and H. J. Hathaway. Estrogen signaling through the transmembrange G protein-could receptor GPR30. Annu. Rev. Phsysiol. 70:165-190.

Pyatt, N. A., G. J. Vogel, J. W. Homm, R. L. Botts, and C. D. Bokenroger. 2013a. Effects of ractopamine hydrochloride on performance and carcass characteristics in finishing heifers: 16-trial summary. J. Anim. Sci. 91(E-Suppl.2):692-693.

Pyatt, N. A., G. J. Vogel, J. W. Homm, R. L. Botts, and C. D. Bokenroger. 2013b. Effects of ractopamine hydrochloride on performance and carcass characteristics in finishing steers: 32-trial summary. J. Anim. Sci. 91(E-Suppl.2):79.

Randall, G. W., and D. J. Mulla. 2001. Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. J. Environ. Qual. 30:337-344.

Rathmann, R. J., J. M. Mehaffey, T. J. Baxa, W. T. Nichols, D. A. Yates, J. P. Hutchenson, J. C. Brooks, B. J. Johnson, and M. F. Miller. 2009. Effects of

duration of zilpaterol hydrochloride and days on the finishing diet on carcass cutability, composition, tenderness, and skeletal muscle gene expression in feedlot steers. J. Anim. Sci. 87:3686-3701.

Ravagnolo, O., and I. Misztal. 2000. Genetic component of heat stress in dairy cattle, parameter estimation. J. Dairy Sci. 83:2126-2130.

Reinhardt, C. 2007. Growth-promotant implants: Managing the tools. Vet. Clin. N. Am. – Food A. 23:309-319.

Rehm, G. W., G. W. Randall, and R. Eliason. 2006. Fertilizing corn in Minnesota. University of Minnesota Extension Serv.

Rhoads, M. L., R. P. Rhoads, M. J. VanBaale, R. J. collier, S. R. Sanders, W. J. Weber, B. A. Crooker, and L. H. Baumgard. 2009. Effect of heat stress and plane of nutrition on lactating Holstein cows: I Production, metabolism, and aspects of circulating somatotropin. J. Dairy Sci. 92:1986-1997.

Rihani, N., W. Garrett, and R. Zinn. 1993. Influence of level of urea and method of supplementation on characteristics of digestion of high-fiber diets by sheep. J. Anim. Sci. 71:1657-1665.

Russel, J. B., J. D. O'Connor, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.

Rusta. S. R., and C. Abneyb. 2005 Comparison of dairy versus beef steers. Pp. 161-174 in Proceedings of Managing and Marketing Quality Holstein Steers. Wis. Agric. Service.Assoc., Madison, WI.

Sandri, M. 2008. Signaling in muscle atrophy and hypertrophy. Physiology. 23:160-170.

Santos, F. A. P., J. E. P Santos, C. B Theurer, and J. T. Huber. 1998. Effects of rumen-undegradable protein on dairy cow performance: A 12-year literature review. J. Dairy Sci. 81:3182-3213.

Sawyer, J. E., B. Lang, and D. W. Barker. 2012. Sulfur fertilization response in Iowa corn and soybean production. Proc. of the 2012 Wisconsin Crop Management Conference.

Sayer, K., C. D. Buckner, G. E. Erickson, T. Klopfenstein, C. Macken, and T. Loy. 2013. Effect of corn bran and steep inclusion in finishing diets on diet digestibility, cattle performance, and nutrient mass balance. J. Anim. Sci. 91:3847-3858.

Scherer, H. 2001. Sulphur in crop production—invited paper. Eur. J. Agron. 14:81-111.

Schroeder, G. F., E. C. Titgeneyer, and E. S. Moore. 2007. Effects of energy supply on leucine utilization by growing steers at two body weights. J. Anim. Sci. 85:3348-3354.

Schroeder, G. F., E. C. Titgemeyer, M. S. Awawdeh, J. S. Smith, and D. P. Gnad. 2006. Effects of energy source on methionine utilization by growing steers. J. Anim. Sci. 84:1505-1511.

Senft, R. L., and L. R. Rittenhouse. 1985. A model of thermal acclimation in cattle. J. Anim. Sci. 61:297-306.

Sharpley, A. N., S. Chapra, R. Wedepohl, J. Sims, T. C. Daniel, and K. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. J. Environ. Qual. 23:437-451.

Sharpley, A., T. Daniel, J. Sims, and D. Pote. 1996. Determining environmentally sound soil phosphorus levels. J. Soil Water Conserv. 51:160-166.

Smith, S. B., S. K. Davis, J. J. Wilson, R. T. Stone, F. Y. Wu, D. K. Garcia, D. K. Lunt, and A. M. Schiavetta. 1995. Bovine fast-twitch myosin light chain 1: cloning and mRNA amount in muscle of cattle treated with clenbuterol. Am. J. Physiol. 268(E-Suppl):858-865.

Smith, S. B., D. K. Garcia, S. K. Davis, and D. B. Anderson. 1989. Elevation of a specific mRNA in longissimus muscle of steers fed ractopamine. J. Anim. Sci. 67:3495-3502.

Solis, J. C., F. M. Beyers, G. T. Schelling, C. R. Long, and L. W. Greene. 1987. Maintenance requirements and energetic efficiency of cows of different breed types. J. Anim. Sci. 66:764-773.

Spiehs, M., and V. Varel. 2009. Nutrient excretion and odorant production in manure from cattle fed corn wet distillers grains with solubles. J. Anim. Sci. 87:2977.

Spiehs, M., B. Woodbury, B. Doran, R. Eigenberg, K. Kohl, V. Varel, E. Berry, and J. Wells. 2011. Environmental conditions in beef deep-bedded mono-slope facilities: A descriptive study. Transactions of the ASABE. 54:663-673.

Strock, J. 2008. Tillage and sulfur management for corn in fine textured soils. Soil Sci. Soc. Am. J. 69:709-717.

Susmel P, M. Spanghero, B. Stefano, C. R. Mills, and E. Plazzotta. 1993. Digestibility and allantoin excretion in cows fed diets differing in nitrogen content. Livestock Prod. Sci. 36:213-222.

Tanabe, R., S. Muroya, and K. Chikuni. 1998. Sequencing of the 2a, 2x, and slow isoforms of the bovine myosin heavy chain and the different expression among muscles. Mammal. Genome. 9:1056-1058.

Tedeschi, L O., D. G. Fox, M. A. Fonseca, L. Francis, and L. Cavalcanti. 2015. Models of protein and amino acid requirements for cattle. R. Bras. Zootec. 44:109-132.

Todd, R. W., N. A. Cole, M. B. Rhoades, D. B. Parker, and K. D. Casey. 2011. Daily, monthly, seasonal, and annual ammonia emissions from southern high plains cattle feedyards. J. Environ. Qual. 40:1090-1095.

USDA. 2011. Feedlot 2011 Part IV: Health and health management on U. S. feedlots with a capacity of 1,000 or more head. Fort Collins: USDA-APHIS-VS-CEAH-NAHMS.

USDA. 2017. National Agriculture Satstics Service. Livestock Slaughter Annual Summary.

Ulyatt, M., D. Dellow, C. Reid, and T. Bauchop. 1975. Structure and function of the large intestine of ruminants. Pp. 119-133 in Digestion and Metabolism in the Ruminant.

Varel, V. H., J. A. Nienaber, and H. C. Freetly. 1999. Conservation of nitrogen in cattle feedlot waste with urease inhibitors. J. Anim. Sci. 77:1162-1168.

Vasconcelos, J. T., R. J. Rathmann, R. R. Reuter, J. Leibovich, J. P. McMeniman, K. E. Hales, T. L. Covey, M. F. Miller, W. T. Nichols, and M. L. Galyean. 2008. Effects of duration of zilpaterol hydrochloride feeding and days on finishing diet on feedlot cattle performance and carcass traits. J. Anim. Sci. 86:2005-2015.

Vernon, B. G., and P. J. Buttery. 1978. The effect of trenbolone acetate with time on the various responses of protein synthesis of the rat. Br. J. Nutr. 40:563-572.

Walker, D. K., and J. S. Drouillard. 2010. Effects of ractopamine hydrochloride are not confined to mammalian tissue: Evidence for direct effects of ractopamine hydrochloride supplementation on fermentation by rumen microorganisms. J. Anim. Sci. 88:697-706.

Walker, D. K., E. C. Titgemeyer, J. S. Drouillard, E. R. Loe, B. E. Depenbusch, and A. S. Webb. 2006. Effects of ractopamine and protein source on growth performance and carcass characteristics of feedlot heifers. J. Anim. Sci. 84:2795-2800.

Walker, D. K., E. C. Titgemeyer, T. J. Baxa, K. Y. Chung, D. E. Johnson, S. B. Laudert, and B. J. Johnson. 2010. Effects of ractopamine and sex on serum metabolites and skeletal muscle gene expression in finishing steers and heifers. J. Anim. Sci. 88:1349-1357.

Wang, X. and C. G. Proud. 2006. The mtor pathway in the control of protein synthesis. Physiology. 21:362-369.

Ward, M. H., T. M. DeKok, P. Levallois, J. Brender, G. Gulis, B. T. Nolan, and J. VanDerslice. 2005. Workgroup report: Drinking-water nitrate and health-recent findings and research needs. Environ. Health Perspect. 113:1607-1614.\

Westerman, P., and R. Zhang. 1997. Aeration of livestock manure slurry and lagoon liquid for odor control: A review. Appl. Eng. Agric. 13:245-249.

Wheelock, J. B., R. P. Rhoads, M. J. Vanbaale, S. R. Sanders, and L. H. Baumgard. 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. J. Dairy Sci. 93:644-655.

Yambayamba, E. S. M. A. Price, and G. R. Foxcroft. 1996. Hormonal status, metabolic changes, and resting metabolic rate in beef heifers undergoing compensatory growth. J. Anim. Sci. 74:57-69.

Yimlamai, T., S. L. Dodd, S. E. Borst, and S. Park. 2005. Clenbuterol induces muscle-specific attenuation of atrophy through effects on the ubiquitin-proteasome pathway. J. Appl. Phys. 99:71-80.

Youself, M. K. 1987. Principle of bioclimatology and adaptation. In Bioclimatology and the adaotation of livestock (ed. H. D. Johnson), Pp. 17-529. Elsevier Science Publisher, Amsterdam, The Netherlands.

Zinn, R. A., A. Barreras, F. N. Owens, and A. Plascenia. 2008. Peformance by feedlot steers and heifers: Daily gain, mature body weight, dry matter intake, and dietary energetics. J. Anim. Sci. 86:2680-2689.

Zinn, R., and F. Owens. 1983. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. J. Anim. Sci. 56:471-475.